Canada Mortgage and Housing Corporation
Société canadienne d'hypothèques et de logement
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RADON EXPOSURES IN FREDERICTON AREA HOUSES AND WELLS FINAL REPORT 1988

Prepared For

The Research Division

Policy Development and Research Sector

Canada Mortgage and Housing Corporation

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Radon Exposures in Fredericton Area Houses and Wells

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Abstract

More than 200 measurements were made of the radon levels in randomly selected Fredericton area homes using charcoal packets typically exposed for 3 days in basements and received and returned by homeowners via Canada Post. Radon levels in well water from 36 of these homes were also determined using a newly developed (for New Brunswick) liquid scintillation technique and homeowner collected water samples. Cold weather airborne radon levels in 50 homes were on the average 30% higher than warm weather values for the same homes. While both water and airborne radon levels varied greatly, none of the water levels exceeded 35,000 picoCuries per litre of water which is well below dangerous levels. The median airborne radon level was 2.70 pCi/L with 30% being above 4 pCi/L and 3.5% above 20 pCi/L, which is roughly the equivalent of the lung cancer risk of smoking a pack of cigarettes per day. The maximum survey level was 45.6 pCi/L. These radon exposures are similar to those determined in numerous recent large surveys in the USA, and in Maine. Overall, they are much higher than those determined in the City of Fredericton during a 1978 summertime, daytime, "grab sample" survey. Country homes had higher levels of radon, with a median of 3.45 pCi/L and 45% exceeding 4 pCi/L. The use of flat, easily mailed and analyzed, charcoal packets offers a simple inexpensive means for monitoring many buildings. The use of homeowner collected, mail distributed, well water samples also offers a suitable technique for water testing.

This project was carried out with the assistance of a grant from Canada Mortgage and Housing Corporation under the terms of the External Research Program. The views expressed are those of the author and do not represent the official views of the Corporation.

Acknowledgements

The principal Investigator wishes to express his sincere gratitude to Peter Russell, CMHC's Project Manager; to the Fredericton area homeowners who provided well water samples and the exposure of radon test packets in their homes, in some cases for two series of measurements; to Keith Davies, Radiation Protection Officer for the Province of New Brunswick who provided both the use of his laboratory equipment and his advice; to Dr. John Sutherland of the New Brunswick Electric Power Commission who provided considerable effort in the development of the liquid scintillation techniques for determining water levels of radon; to Ms. Cheryl Baker of the State of Maine Health Services Department for considerable information and the exposure of test packets in her radon chamber and to Rod Henderson and many others at Neill and Gunter Limited who were helpful throughout this research program. Dozens of other persons have also provided copies of their papers which have helped in providing a sense of perspective for this most interesting project.

Radon Exposures in Fredericton Area Houses and Wells
Executive Summary

As a result of a very considerable effort over the past decade a great deal of information about the levels of radon in homes across North America has been obtained. Two major conclusions have been derived from these hundreds of thousands of measurements. The first is that home exposure to radioactive radon gas and its solid radioactive daughters is the major source of radiation exposure to the great majority of people living in Canada. The second conclusion of at least some researchers is that radon is by far the most significant environmental pollutant in terms of the number of premature deaths to which it contributes.

Because the public health concern is no longer limited to that small percentage of the population working in uranium (or similar) mines, it has become necessary to develop techniques which would allow anyone to find out at minimal cost the radon level in an individual home and, where appropriate, in the well water used by that home. The measurements made during this research effort sponsored by the Canada Mortgage and Housing Corporation were directed towards the goal of evaluating a technique already in very widespread use in the United States namely the use of charcoal packets exposed in homes for three days by homeowners and eliminating the use of home visits by trained investigators using expensive equipment that only allows for instantaneous measurements as opposed to the much more desirable and useful time-integrating data provided by the charcoal.

Almost 500 randomly selected homeowners in the Greater Fredericton area were solicited by mail for their participation in a free home radon testing program. Respondents filled out a simple questionnaire providing information on the age, size, relative insulation and home heating system type as well as the use of city or well water. In 50 homes measurements were made both in warm weather and during cold weather to help evaluate the seasonal differences.

With the considerable co-operation of the Radiation Protection Officer of New Brunswick and assistance from other professional persons in the area as well as in the State of Maine, a straight forward monitoring procedure was evolved similar to that in wide use now in the United States, but not yet widely adopted in Canada. Small (40 gram) flat charcoal packets were mailed to participants and returned by mail after exposure. These were analyzed in the laboratory using radiation detection apparatus. Calibrations were performed using a radon chamber in Maine. Total instrument time in the laboratory for an individual packet was about 5 minutes. A technician could be easily trained to operate the equipment. With multiple laboratory counting systems it would easily be possible to do hundreds or thousands of readouts per day for a very large scale screening survey at a cost below $20 per sample.

As expected the test results demonstrated that radon levels vary widely (more than a factor of 50), that country homes in general had higher levels than did city homes, that winter values were higher than fall values.

The 1978 Cross Canada survey covered 455 homes in the City of Fredericton. The median radon level was 0.66 pCi/L. Only 21.5% exceeded 2.0 pCi/L and 6.8% exceeded 4.0 pCi/L. The current series of integrating measurements showed that even including the warm weather data, 66% were greater than 2.0 pCi/L, that 30% exceeded 4.0 pCi/L and that 3.5% exceeded 20 pCi/L. It was also found that while the overall median value was 2.70 pCi/L, the median for homes with wells, and therefore outside the City, was 3.45 pCi/L. The median for homes without wells was 2.29 pCi/L. The current series of measurements falls into line with other surveys including those made in the adjacent State of Maine and even some little known test series done in Canada.

Based upon the fact that hundreds of private companies make charcoal based radon measurements in the United States and also have been able to reduce radon levels to below 4 pCi/L at very low costs (typically less than $1,000), most such information could probably be obtained at the expense of the homeowner. It may be necessary for the government to take the lead in educating the public about radon and in regulating testing laboratories, in suggesting a standard testing and mitigation agreement and possible legislation. The EPA has been the lead agency in the USA regarding radon, but has had assistance from many other laboratories. There is no reason that the Canadian government cannot take advantage of the EPA's substantial expenditures to reduce the effects of excessive radon exposure in Canada while avoiding the huge costs associated with the past removal of UFFI which, after all, provided much less of a threat to the physical health of the public.

To put the problem in perspective, a very detailed study published by the National Academy of Sciences in the USA in January, 1988, indicated that probably there are 13,000 American deaths per year from lung cancer partly or completely induced by long term exposure to radon, often in conjunction with smoking since the effect of the two is multiplicative (in some way) rather than additive. Canada has only 1/10 the population of the U.S., but is the world's largest exporter of uranium and certainly, on the average, has longer harsher winters than does the U.S. On that basis, it would appear that more than 1,000 Canadians per year are dying from exposure to radon. However, there are as yet no known comparable situations in Canada to the Reading Prong of large populations being exposed to high levels.

The radon levels measured in well water samples from the Fredericton area varied greatly, but none exceeded 35,000 pCi/L of water. This indicates that not much of the airborne radon measured in those homes can be introduced in the homes via the water. There was concern in this regard because Maine has some of the highest well water radon levels in the world and there is similar geology in some areas of New Brunswick. The technique used for the water evaluation is very similar to that used in Maine which provides both a customer-paid, mail-order approach to well water testing for radon and also uses Charcoal (canisters not packets) on a mail order fee-for-service basis for determining airborne radon levels.

As a general conclusion based upon the measurements described in this report and the information obtained during the past year, inexpensive techniques are at hand for time integrated monitoring of Radon in homes and in well water using central laboratories on a commercial basis with mail order service. There is an excellent basis for the belief that a significant number of Canadians are being exposed to much higher risk of lung cancer from home radon than had previously been anticipated. Work done elsewhere clearly indicates that the radon problem is a solvable problem, that mitigation is feasible at reasonable costs, and that homeowners will, in general, be willing to pay for their own testing and mitigation given sufficient information about the risks and costs and an opportunity to contract for services. As an indication of the very rapid growth in the private radon monitoring and mitigation business, the EPA has been completely swamped by more than 1100 private companies asking to participate in Round 5 of the EPA National Radon Measurement Proficiency Program now already required for testers in New York, New Jersey, Pennsylvania and Nebraska.

Radon Exposures in Fredericton Area Houses and Wells

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Final Report - Radon Exposure in Fredericton Area Houses and Wells

Stanton T. Friedman, Principal Investigator

Background

Radon

Radon is a very heavy, colourless, odorless, tasteless chemically inert gas. It would be of little interest except as a laboratory curiosity if it were not for the fact that it is also radioactive. Radon was discovered in 1900. It is present in the land areas of the planet, in greater or lesser quantities, essentially everywhere. It is produced as a result of the radioactive decay of radium which in turn is produced by the decay of uranium. Since uranium has a half life that is extraordinarily long, measured in billions of years, and radium has a half life of about 1600 years, radon as a gas is the odd ball in the series having a half life of only 3.8 days or about 92 hours. This is long enough for the radon generated by radium decay within many feet of a home to migrate in soil gas and enter that home.

There were only two minor applications for radon prior to the concern with it as a lung cancer inducing agent. First it was found that because of its emission of highly energetic alpha particles which can be absorbed by a relatively small thickness of tissue it would be useful for the treatment of cancers. Radon was encapsulated in tiny glass "seeds" which were implanted near tumors. The alpha particles would help to destroy the tumors. Because of the short half life there would be no need for extraction of the seeds. This use has long since been replaced by treatment with other sources of radiation either Cobalt 60, electrons or x-rays from accelerators, or Cesium 137 implants. These are much more readily available than is radon.

A second application for radon, again because of its radioactivity, was as a marker for deposits of uranium. From a prospecting viewpoint finding higher than usual levels of radon near the surface of the earth might be taken as an indicator that there was more than the usual concentration of uranium in land below that point. Radon in water has also been used as a marker for possible uranium deposits. It should be stressed that radon is quite soluable in water which means that it can be rapidly transported a long way in significant quantities by water.

Most radon escapes into the soil gas surrounding the rock where it is produced and is eventually released into the atmosphere where it is very highly diluted. However, it is the radon that gets into closed areas in which humans are present such as homes and mines that was of concern for this research project.

The history of concern with radon as a cancer inducing agent has changed dramatically over the past 40 years. It had been recognized hundreds of years ago that miners in certain areas in Europe died at an early age of a peculiar lung disease. Less than one hundred years ago this was eventually identified as lung cancer. Less than eighty years ago it was suggested that the lung cancer was induced by radon daughters present in high concentration in poorly ventilated mines. Post World War II when, because of the atom bomb and nuclear power projects, there was a widespread effort to mine whatever uranium was available, there was a focus on the potential hazards to uranium miners. Subsequently it was determined that a number of houses had been built on mine tailings, especially in Colorado. The concern was that there

might be excessive radon level in the homes built on radioactive mine tailings. Finally in the 1980's there has been an initially slowly growing recognition that not only could radon levels be high in homes built on mine tailings or in homes built using materials that had a high level of uranium, but even in homes that had NO connection with uranium mining and no materials containing a high level of uranium such as certain kinds of gyprock made from gypsum contaminated with uranium.

The focal point of worldwide publicity for radon as a hazard in peoples homes unconnected with the mining industry was the experience widely reported of engineer Stanley Watras who set off radiation monitors at the Limerick Nuclear plant in Pennsylvania where he was employed, on the way into work. This happened a number of times. Finally an investigation in late 1984 determined that the radon level in his house, located on the "Reading Prong" geological formation was exceedingly high and the radon daughters which are solids (rather than gases) which accumulated on his clothing, his hair, etc. were setting off the radiation detectors. This initial discovery, a kind of man-bites-dog story, received very wide publicity even though it was not the first instance of high levels in homes being noted. Dr. Fleischer of General Electric had published a number of letters and papers in Physics Today in the early 1980's denoting this potentially large hazard to human health.

Measurements made in other homes on the so-called "Reading Prong" indicated that there were a number of homes with relatively high radon levels. The common way of expressing these was a lung cancer hazard equivalent to that from smoking perhaps 100 packs of cigarettes per day!! This publicity has resulted in hundreds of thousands of measurements in the United States and tens of thousands in other countries. Almost everywhere that large scale screening measurements have been done, there has been found a certain fraction of homes with excessive levels of radon. The question is how big is this fraction? How dangerous is the radon? Is there something that can be done to prevent it? How does one determine what the distribution is?

Units of Measurement

Any discussion of radon rapidly gets to the point where the units used to measure the radon levels need to be discussed. The situation is very confusing. Initially the concern was with miners who would be exposed for a limited amount of time, typically 40 hours per week as opposed to the home situation in which there would be people who were not only healthy workers, but also young and old men and women and pregnant women exposed, in many cases, for perhaps 120 or more hours per week. Since early medical hazard studies were done with miners which implies only a male population in reasonably good health between the ages of say 18 and 60, there are still questions about the applicability of these data to the general population.

Two units for measuring radon levels are in fairly common useage. One is in terms of picoCuries/litre of air the other becquerels/cu.m. of air. This is for radon gas. A Curie is the amount of radioactivity associated with a gram of radium, which was discovered by Marie Curie. A picoCurie is a trillionth of a Curie, a very small unit indeed. Home values run from perhaps 0.5 picoCuries/litre (pCi/L) up to as high as 2200 pCi/L. Median levels are usually under 4 pCi/L. A Becquerel is the name of the new unit used to describe 1 radioactive disintegration per second. Since a Curie represents 3.3×10^{10} disintegrations per second, a Becquerel is indeed a very small unit of radioactivity as is a picoCurie. The two units are, of course, interchangeable as long as one corrects for the different volumes. One pCi/L = 37 Becquerels/cubic metre of air.

A much more complicated unit is the Working Level Month. This relates directly to the mining situation and reflects the exposure to radon daughters which are the agents that actually induce the lung cancer as opposed to the radon gas. It has to be assumed that there is some kind of equilibrium ratio between radon and its daughters. The daughters have very short half lives measured in minutes. They, too, emit alpha particles and they finally decay to Lead-210. The question is whether there is a constant ratio of radon to radon daughters since it would depend (because the daughters are electrically charged) on the number of particles, dust, etc. in the environment, the flow of the gas, and a number of other variables. In any event it is clear that the absolute quantity of radon involved, even in a high level house, is extraordinarily small. 1 pCi/L is roughly 2 atoms per litre.

It is quite incredible to many people that such a small quantity of gas could provide danger to people breathing such small quantities.

Measurements of Radon Levels in Canadian Homes

Because Canada is the world's largest exporter of uranium, it certainly employed a great number of people in uranium mines post World War II. Therefore, it is not surprising that there was concern with the health effects on the miners of potentially high levels of radon gas in the mines. These levels, in general, were reduced by using appropriate ventilation techniques. Gradually, as the focus shifted from the mines to the homes of the miners, it was recognized that there was a need for information on radon levels in normal (control) houses away from mining areas and not built on mine tailings and not using uranium bearing materials in the construction. In order to get an indication of what levels were and their variation from region to region Health and Welfare Canada in the late 1970's did one of the earliest large scale surveys of home radon levels ever done anywhere.

The measurements that were made were done by a group of summer students hired through Employment Canada to make measurements in 19 large cities (originally 14) across the country. All measurements were made using "grab sample" techniques. These involve pumping air through a filter for a specified amount of time of 5 minutes (and therefore a specified air volume) then analyzing the radon daughters retained on the filter. In addition, in order to determine the radon level, as opposed to the radon daughter levels, Lucas cells were employed. These involve the collection in a small volume (often 150 cc's) of an air sample from the room in question. The walls of the cell are coated with a fluorescing substance such as zinc sulphide. These are then placed in a device which analyzes, in effect, the light produced by the interaction of the energetic radioactive decay particles with the zinc sulphide. From this one can infer how much radioactivity was present in the volume of the cell.

A home sampling technique was employed using census tracts with the student groups sampling the air in every tenth house on the longest street in a particular census tract. The attention was restricted initially to fourteen cities with 5 more cities added. A total of more than 14,000 measurements were made and the results reported in a number of papers produced by scientists of Health and Welfare Canada. The test results did give an indication that there was considerable variation in both the average level from city to city and particularly within a city between the minimum and maximum levels that were measured. They provided a basis for estimating how many homes might have an excessive level,

whatever standard was set, and where one might look for high level homes. There were, however, a number of limitations associated with these measurements. These are tabulated below:

1. There are only instantaneous values. But the connection between these values and the overall year-round average level in a particular residence is not well established. Conceivably these could vary greatly from region to region and from home to home, since it is now known that radon levels can vary greatly from night to day, and from summer to winter depending on weather conditions, heating conditions, whether the house is closed or open, etc.,
2. Subsequent measurements have shown that typically values are higher in the winter than in the summer when the measurements were taken especially in regions such as New Brunswick which include very few homes with air conditioning. (i.e. they typically have open windows and, therefore, high rates of air change). The last column in Table 1 illustrates the problem.
3. Subsequent measurements have established that typically values are higher at night than in the day because there is a greater temperature difference and that radon levels in a home are related to pressure differences between the soil surrounding the house and the house itself. See Figure 1.
4. The measurements were all made in cities for simplicity. This means that almost none of the homes had <u>private</u> water wells which could provide radon gas dissolved in the water and introduced into the house by the private wells. City

TABLE 1

Spokane, WA, Area Home Radon Test Results

HOUSE ID	WATER SUPPLY SOURCE[a]	WATER SUPPLY RADON (pCi/l)	SOIL GAS[b] RADON (pCi/l)	BUILDING MATERIAL EMANATION[c] (pCi/m^2/sec)	INDOOR AIR (pCi/l) SUMMER 85[d]	INDOOR AIR (pCi/l) WINTER SEASON 84-86[e]	Ratio Winter/ Summer (STF)
ECD026C	W	900	277-385	NA	1.1	17.2	15.6
ECD027	W	2920	284-464	5.13	3.8	45.0	11.8
ECD153	W	250	630-658	0.10	1.0	24.2	24.2
ESP101	M	550	314-383	0.21	3.5	27.6	7.9
ESP108C	M	830	340-487	NA	4.3	15.3	3.6
ESP109	M	670	NA	NA	1.6	6.9	3.8
ESP111	M	370	306-353	NA	0.9	29.6	32.9
ESP113	M	570	420-426	NA	3.7	23.0	6.2
ESP116	M	550	374-521	0.06	NA	23.6	X
ESP119	M	460	396-400	NA	NA	49.4	X
ESP120	M	500	311-610	0.23	11.9	132.0	11.1
ESP121	M	560	NA	NA	1.2	11.2	9.3
EVA604	W	610	620-626	0.05	0.9	10.4	11.6
						Overall Average R	12.5

(a) W = Well, M = Municipal

(b) Range of values obtained at a depth of 1.0 - 1.5 meters from December 1985 grab samples

(c) Maximum value of all floor, wall or other measurements

(d) Passive Monitors

(e) Average for intermittent continuous monitoring throughout the months November - March

Source: "Radon and Remedial Action in Spokane River Valley Residences:An Interim Report" by B.H. Turk and associates, Lawrence Berkeley Laboratory, Univ. of California Presented at APCA Annual Meeting, June 1986, Minneapolis, MN LBL-21399 (23p.,12Ref. 3 Tables, 5Figures.

FIGURE 1

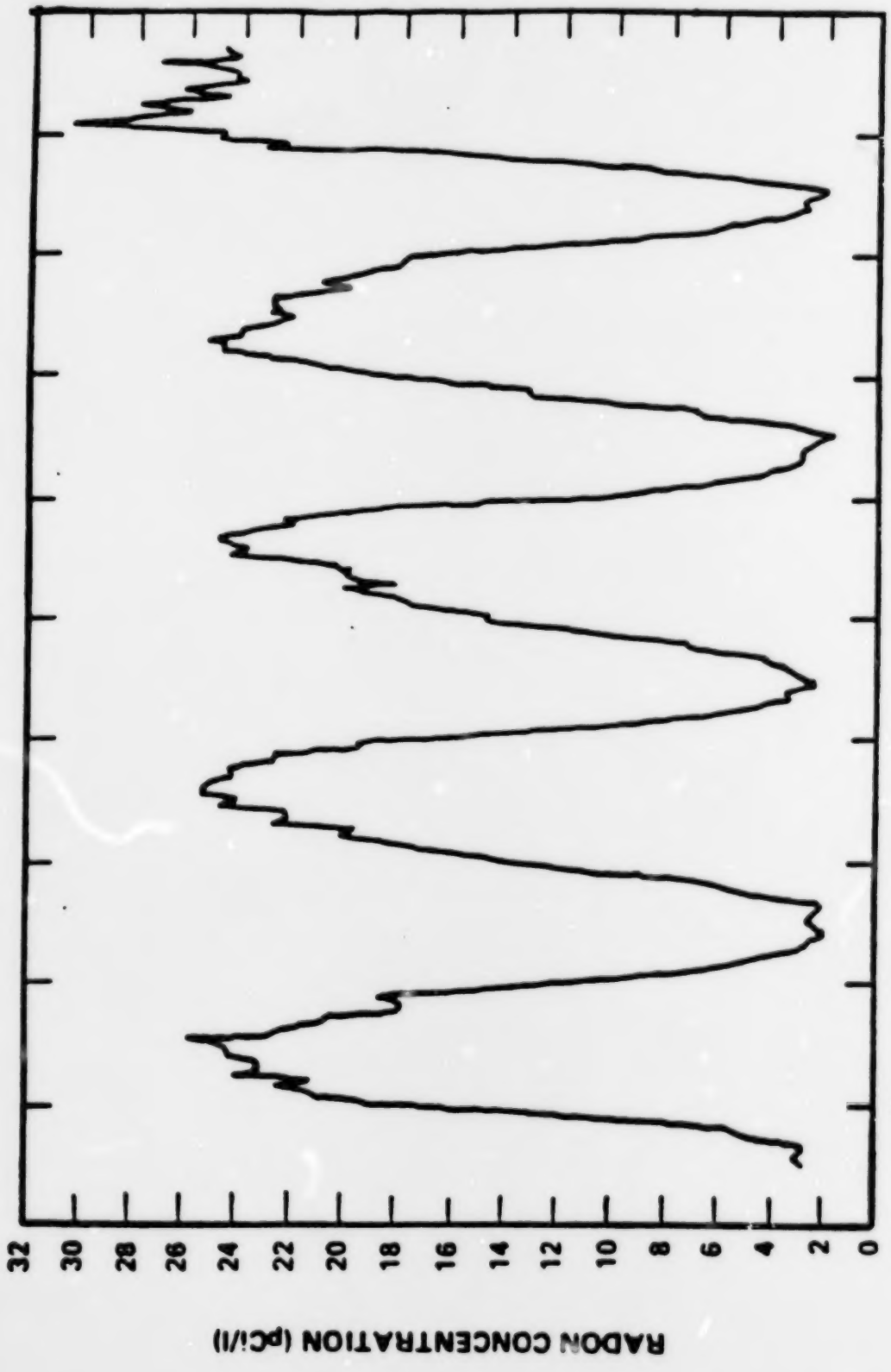

Figure 1. Example of diurnal variation. House in Clinton, New Jersey.

Source: Osborne, M.C. "Four Common Diagnostic Problems that Inhibit Radon Mitigation", Journal of the Air Pollution Control Association, Vol. 37, No. 5, May 1987, pp. 604-606.

water supplies and surface water supplies are known not to have high levels of radon. The age distribution of the homes conceivably could be very different in the major cities as opposed to that in the country. Subsequent measurements have indicated that country values would be considerably higher than city values on the average.

5. Because only 19 cities were sampled, it is not very likely that radon hot spots would have been caught. The Reading Prong, for example certainly would not have been picked up in such a survey in the U.S.A. Neither would the half dozen homes in Clinton, New Jersey having more than 2,000 pCi/L.
6. There was apparently no standard protocol for the ventilation status of the home during the measurements made by the test crews. The EPA has established such standards for its huge screening program. Normally windows are closed for 12 hours prior to and during a 2-7 day integrating measurement.

In an attempt to take into account knowledge and technology developed since those initial survey results were obtained, the present survey project was conducted.

Methodology

In order to provide other than instantaneous values an integrating technique was used which enabled all aspects of the measurements to be done locally in the Fredericton area. There are at least 4 different techniques available for monitoring radon. 1. The use of "grab" samples which requires especially

trained personnel to visit test homes; also instantaneous reading devices (such as Thompson-Neilsen instrument); 2. The use of expensive continuous electronic monitoring devices left in place recording the radon values every hour or two hours on a periodic basis over an extended period of time and determining an average value; 3. The use of Track Etch detectors - small pieces of film wherein tracks countable using a microscope are produced by the passage of the alpha particles from the radon or radon daughters. These normally are sufficiently insensitive that they need to be put in place for a 3 month period prior to readout. They can be sent and returned by mail. These have a real advantage in giving a radon value that is much closer to what people would experience while living in the home, although, of course, it doesn't distinguish between day and night. Students and adults working outside the home are obviously not present as much during the day as they are at night. 4. The use of "activated" charcoal to absorb radon over a period of time (2-7 days) with the radioactivity from the absorbed radon daughters being measurable in a relatively readily available test analysis facility using a lead shield to reduce background radiation.

The use of charcoal, which has only been widespread for about the last 6 years, offers a number of advantages: The results can be obtained by mail; that is, the sample packet can be mailed to the recipient, put in place by the recipient without any special training; returned by mail and then analyzed in a laboratory without the use of highly skilled personnel for taking the sample,

travelling between test locations, etc. This procedure concentrates the skills in the laboratory rather than on the road. The major advantage over Track Etch is the much shorter exposure time.

Two different approaches have been widely used to the point where several hundred companies in the United States are currently using charcoal as the mechanism for determining radon levels, partly because the Environmental Protection Agency has accepted the use of charcoal as a screening technique.

The two methods involve either the charcoal canister or the charcoal packet. Canisters come in several sizes, usually 7.5 - 10 cm in diameter and approximately 2.4 cm thick. Cans commercially manufactured for salves and various other preparations are used to hold a layer of charcoal with a metal mesh screen to retain the charcoal and sometimes with a diffusion barrier. The can is opened, the top removed, exposed typically in a basement for anywhere from 2 - 7 days, closed, and sent back to the laboratory for analysis. The packets normally are of paper, roughly 12-15 cm square, roughly 1 cm thick and are mailed in foil envelopes so that the only time that the charcoal is exposed to the radon, which must penetrate through the paper packaging, is when the packet is taken out of the foil envelope. There are pros and cons to both techniques. A pioneer in the wide scale measurement of radon levels is Dr. Bernard Cohen at the University of Pittsburgh. He has been using the relatively small (and much less sensitive) canisters with the diffusion barrier. AirChek in North

Carolina has been the major distributor of the charcoal packets. The cans are sturdier, of course, and there is very little danger of penetration of the can in the course of shipping. They have been demonstrated to give reasonably reliable results and they are reuseable if they are heated to drive off absorbed moisture and radon and weighed before reuse.

Initial evaluation of both techniques requires consideration of a number of factors. Competition for adsorption on the charcoal comes from moisture. In summer with high humidity, the charcoal can adsorb far more moisture than it does radon since the quantities of radon involved are so terribly small. Thus there needs to be a correction for that absorption. Two, every kind of charcoal seems to be a little different in its ability to both adsorb and withhold radon. There is a dynamic process going on in other words where radon is adsorbed. Depending on temperature and other circumstances, some of the adsorbed material will be released. In both cases one uses exactly the same technique for analysis. That is exposure of the packet or the can within a shielded enclosure in which there is typically a 3 inch x 3 inch or larger sodium iodide crystal which determines the total number of gamma rays originating in the charcoal source. Standardized calibrations are done with exposure of charcoal in a standard radon chamber so that one can associate a particular counting rate, after correction for background levels, with a particular exposure to radon. In addition one must take into account the decay since the end of the exposure. Because of the latter problem, it is import-

ant that the charcoal samples be received as soon as possible after the end of the test device exposure in the home.

With the half life of 3.8 days, typically receipt within a week will allow for adequate statistics to determine the radon levels. In the case of the canisters, one not only weighs the canister beforehand, but also after it is heated and prior to reuse. The greater the weight of the charcoal in a particular packet or canister the more radon will be adsorbed. This correction typically is quite small since quality control would indicate that the total weight of charcoal for packets might be 40$\pm$ 2 grams. For the larger canister, it might be 70$\pm$ 2 grams.

A very important consideration with regard to measurements of radon or radon daughters is the fact that many measurements made in different countries and residences clearly establish that the radon level varies significantly with time, with weather conditions, and a whole host of other variables. Thus it is inappropriate, especially for a screening measurement, to try to force laboratory standards on measurements of home radon levels.

This is an important point since what is important is whether the radon level is for example below 4 pCi/L between 4 and 20 or between 20 and 200 or over 200. It is of no particular utility to know that the radon level is 12.685 pCi/L as opposed to knowing that it is 12$\pm$ 2 pCi/L since it seems almost certain that the next time a measurement is made, no matter what technique is used, the value would turn out to be slightly different. In addition there are great many uncertainties related to associating the radon

level, even measured over a several day period, with the total exposure of a person over many years. A key feature of the radon induced health problem is that there is a very long latency period, anywhere from 10 to 30 years, for lung cancer and that there are no symptoms associated with the exposure to radon other than the eventual development of lung cancer and that in the course of those many years there will be differences in the residence time of various members of a household. There will be differences in the weather conditions, one year to the next, so it is not a requirement that the measurements take into account all possible confounding variables so long as their influence is small.

Test Results

All of the individual home radon measurements are listed in Appendix 1. Essentially all test packets were exposed in basements. Table 2 summarizes the results of the tests as a function of certain variables using the data base computer program developed during this research effort and described in Appendix B. The "A" houses were those that were tested in the early fall. These same houses tested later on when it was mid- winter are listed as "B" houses. All the other houses were tested in the winter, and are "C" houses. A comparison between "A" and "B" test results is given in Table 3. On the average, the winter reading for the same home was 1.3 times greater than the fall reading for that time. This is reasonably consistant with other results in other locations having a climate not too different from New Brunswick.

TABLE 2
Fredericton Area Home Radon Test Results

DATA RANGE : ALL 'A' PACKETS Exposed prior to Winter

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
50	0 - 2 pCi/L	19	38	38	4.14	2.55	25.00
	2 - 4	18	36	74			
	4 - 16	11	22	96			
	OVER 16	2	4	100	PCNT > 4.0 pCi/L= 26		

DATA RANGE : ALL 'B' PACKETS Winter exposures in same houses as "A" packets

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
51	0 - 2 pCi/L	19	37	37	4.44	2.83	28.16
	2 - 4	16	31	69			
	4 - 16	14	27	96			
	OVER 16	2	4	100	PCNT > 4.0 pCi/L= 31		

DATA RANGE : ALL 'C' PACKETS Winter exposures, non "A"

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
100	0 - 2 pCi/L	31	31	31	5.23	2.76	45.58
	2 - 4	37	37	68			
	4 - 16	27	27	95			
	OVER 16	5	5	100	PCNT > 4.0 pCi/L= 32		

DATA RANGE : ALL 'B' AND 'C' PACKETS

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
151	0 - 2 pCi/L	50	33	33	4.96	2.78	45.58
	2 - 4	53	35	68			
	4 - 16	41	27	95			
	OVER 16	7	5	100	PCNT > 4.0 pCi/L= 32		

DATA RANGE : ALL A, B, AND C PACKETS

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
201	0 - 2 pCi/L	69	34	34	4.76	2.70	45.58
	2 - 4	71	35	70			
	4 - 16	52	26	96			
	OVER 16	9	4	100	PCNT > 4.0 pCi/L= 30		

TABLE 2

Test Results (Continued)

DATA RANGE : HOUSES WITH WELL - ALL 'A' PACKETS

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
16	0 - 2 pCi/L	5	31	31	6.46	3.20	25.00
	2 - 4	4	25	56			
	4 - 16	5	31	88			
	OVER 16	2	12	100	PCNT > 4.0 pCi/L= 44		

DATA RANGE : HOUSES WITH WELL - ALL 'B' PACKETS

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
18	0 - 2 pCi/L	5	28	28	6.81	3.91	28.16
	2 - 4	4	22	50			
	4 - 16	7	39	89			
	OVER 16	2	11	100	PCNT > 4.0 pCi/L= 50		

DATA RANGE : HOUSES WITH WELL - ALL 'C' PACKETS

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
57	0 - 2 pCi/L	13	23	23	6.79	3.21	45.58
	2 - 4	19	33	56			
	4 - 16	20	35	91			
	OVER 16	5	9	100	PCNT > 4.0 pCi/L= 44		

DATA RANGE : HOUSES WITH WELL - ALL 'B' AND 'C' PACKETS

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
75	0 - 2 pCi/L	18	24	24	6.60	3.48	45.58
	2 - 4	23	31	55			
	4 - 16	27	36	91			
	OVER 16	7	9	100	PCNT > 4.0 pCi/L= 45		

DATA RANGE : HOUSES WITH WELL - ALL 'A', 'B', AND 'C' PACKETS

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
91	0 - 2 pCi/L	23	25	25	6.74	3.45	45.58
	2 - 4	27	30	55			
	4 - 16	32	35	90			
	OVER 16	9	10	100	PCNT > 4.0 pCi/L= 45		

TABLE 2

Test Results (Continued)

DATA RANGE : HOUSES WITHOUT WELL - ALL 'A' PACKETS

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
35	0 - 2 pCi/L	14	40	40	3.05	2.17	14.68
	2 - 4	15	43	83			
	4 - 16	6	17	100			
	OVER 16	0	0	100	PCNT > 4.0 pCi/L= 17		

DATA RANGE : HOUSES WITHOUT WELL - ALL 'B' PACKETS

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
34	0 - 2 pCi/L	14	41	41	3.13	2.38	14.86
	2 - 4	13	38	79			
	4 - 16	7	21	100			
	OVER 16	0	0	100	PCNT > 4.0 pCi/L= 21		

DATA RANGE : HOUSES WITHOUT WELL - ALL 'C' PACKETS

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
43	0 - 2 pCi/L	18	42	42	3.14	2.25	15.40
	2 - 4	18	42	84			
	4 - 16	7	16	100			
	OVER 16	0	0	100	PCNT > 4.0 pCi/L= 16		

DATA RANGE : HOUSES WITHOUT WELL - ALL 'B' AND 'C' PACKETS

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
77	0 - 2 pCi/L	32	42	42	3.13	2.29	15.40
	2 - 4	31	40	82			
	4 - 16	14	18	100			
	OVER 16	0	0	100	PCNT > 4.0 pCi/L= 18		

DATA RANGE : HOUSES WITHOUT WELL - ALL 'A', 'B' AND 'C' PACKETS

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
112	0 - 2 pCi/L	46	41	41	3.11	2.25	15.40
	2 - 4	46	41	82			
	4 - 16	20	18	100			
	OVER 16	0	0	100	PCNT > 4.0 pCi/L= 18		

TABLE 2

Test Results (Continued)

DATA RANGE : ALL HOUSES WITH HEAVY INSULATION

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
31	0 - 2 pCi/L	11	35	35	4.37	2.85	14.86
	2 - 4	9	29	65			
	4 - 16	11	35	100			
	OVER 16	0	0	100	PCNT > 4.0 pCi/L= 35		

DATA RANGE : ALL HOUSES WITH MEDIUM INSULATION

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
142	0 - 2 pCi/L	52	37	37	4.79	2.64	40.41
	2 - 4	50	35	72			
	4 - 16	32	23	94			
	OVER 16	8	6	100	PCNT > 4.0 pCi/L= 28		

DATA RANGE : ALL HOUSES WITH LIGHT INSULATION

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
25	0 - 2 pCi/L	6	24	24	5.29	3.62	45.58
	2 - 4	9	36	60			
	4 - 16	9	36	96			
	OVER 16	1	4	100	PCNT > 4.0 pCi/L= 40		

DATA RANGE : ALL HOUSES LESS THAN 5 YEARS OLD

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
34	0 - 2 pCi/L	9	26	26	4.75	3.06	20.50
	2 - 4	13	38	65			
	4 - 16	11	32	97			
	OVER 16	1	3	100	PCNT > 4.0 pCi/L= 35		

DATA RANGE : ALL HOUSES BETWEEN 5 AND 10 YEARS OLD

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
21	0 - 2 pCi/L	8	38	38	4.79	2.83	34.00
	2 - 4	7	33	71			
	4 - 16	5	24	95			
	OVER 16	1	5	100	PCNT > 4.0 pCi/L= 29		

TABLE 2

Test Results (Continued)

DATA RANGE : ALL HOUSES BETWEEN 10 AND 20 YEARS OLD

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
51	0 - 2 pCi/L	28	55	55	3.37	1.90	20.57
	2 - 4	13	25	80			
	4 - 16	8	16	96			
	OVER 16	2	4	100	PCNT > 4.0 pCi/L= 20		

DATA RANGE : ALL HOUSES OVER 20 YEARS OLD

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
92	0 - 2 pCi/L	24	26	26	5.55	3.29	45.58
	2 - 4	36	39	65			
	4 - 16	27	29	95			
	OVER 16	5	5	100	PCNT > 4.0 pCi/L= 35		

DATA RANGE : ALL HOUSES UNDER 1000 SQ.FT.

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
17	0 - 2 pCi/L	5	29	29	3.74	3.45	8.86
	2 - 4	6	35	65			
	4 - 16	6	35	100			
	OVER 16	0	0	100	PCNT > 4.0 pCi/L= 35		

DATA RANGE : ALL HOUSES BETWEEN 1000 AND 2000 SQ.FT.

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
137	0 - 2 pCi/L	53	39	39	4.57	2.51	45.58
	2 - 4	41	30	69			
	4 - 16	38	28	96			
	OVER 16	5	4	100	PCNT > 4.0 pCi/L= 31		

DATA RANGE : ALL HOUSES OVER 2000 SQ.FT.

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
44	0 - 2 pCi/L	11	25	25	5.81	2.90	30.00
	2 - 4	22	50	75			
	4 - 16	7	16	91			
	OVER 16	4	9	100	PCNT > 4.0 pCi/L= 25		

TABLE 2

Test Results (Continued)

DATA RANGE : HOUSES LESS THAN 5 YEARS OLD - WITH WELL

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
18	0 - 2 pCi/L	3	17	17	5.23	3.19	20.50
	2 - 4	8	44	61			
	4 - 16	6	33	94			
	OVER 16	1	6	100	PCNT > 4.0 pCi/L = 39		

DATA RANGE : HOUSES BETWEEN 5 AND 10 YEARS OLD - WITH WELL

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
16	0 - 2 pCi/L	4	25	25	5.74	3.18	34.00
	2 - 4	6	38	62			
	4 - 16	5	31	94			
	OVER 16	1	6	100	PCNT>4.0 pCi/L = 38		

DATA RANGE : HOUSES BETWEEN 10 AND 20 YEARS OLD - WITH WELL

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
24	0 - 2 pCi/L	10	42	42	4.77	2.20	20.57
	2 - 4	6	25	67			
	4 - 16	6	25	92			
	OVER 16	2	8	100	PCNT>4.0 pCi/L = 33		

DATA RANGE : HOUSES OVER 20 YEARS OLD - WITH WELL

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
33	0 - 2 pCi/L	6	18	18	9.47	4.88	45.58
	2 - 4	7	21	39			
	4 - 16	15	45	85			
	OVER 16	5	15	100	PCNT>4.0 pCi/L = 61		

DATA RANGE : HOUSES UNDER 1000 SQ.FT - WITHOUT WELL

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
10	0 - 2 pCi/L	2	20	20	3.91	3.56	8.27
	2 - 4	4	40	60			
	4 - 16	4	40	100			
	OVER 16	0	0	100	PCNT>4.0 pCi/L = 40		

TABLE 2

Test Results (Continued)

DATA RANGE : HOUSES BETWEEN 10 AND 20 YEARS OLD - ALL PACKETS

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
51	0 - 2 pCi/L	28	55	55	3.37	1.90	20.57
	2 - 4	13	25	80			
	4 - 16	8	16	96			
	OVER 16	2	4	100	PCNT > 4.0	pCi/L = 20	

DATA RANGE : HOUSES OVER 20 YEARS OLD - ALL PACKETS

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
92	0 - 2 pCi/L	24	26	26	5.55	3.29	45.58
	2 - 4	36	39	65			
	4 - 16	27	29	95			
	OVER 16	5	5	100	PCNT>4.0	pCi/L = 35	

DATA RANGE : HOUSES LESS THAN 1000 SQ. FT.

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
17	0 - 2 pCi/L	5	29	29	3.74	3.45	8.86
	2 - 4	6	35	65			
	4 - 16	6	35	100			
	OVER 16	0	0	100	PCNT>4.0	pCi/L = 35	

DATA RANGE : HOUSES BETWEEN 1000 AND 2000 SQ. FT.

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
137	0 - 2 pCi/L	53	39	39	4.57	2.51	45.58
	2 - 4	41	30	69			
	4 - 16	38	28	96			
	OVER 16	5	4	100	PCNT>4.0	pCi/L = 31	

DATA RANGE : HOUSES OVER 2000 SQ. FT.

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
44	0 - 2 pCi/L	11	25	25	5.81	2.78	30.00
	2 - 4	22	50	75			
	4 - 16	7	16	91			
	OVER 16	4	9	100	PCNT>4.0	pCi/L = 25	

TABLE 2

Test Results (Continued)

DATA RANGE : HOUSES BETWEEN 1000 AND 2000 SQ.FT. - WITHOUT WELL

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
72	0 - 2 pCi/L	34	47	47	2.86	2.13	15.40
	2 - 4	26	36	83			
	4 - 16	12	17	100			
	OVER 16	0	0	100	PCNT > 4.0 pCi/L = 17		

DATA RANGE : HOUSES OVER 2000 SQ.FT. - WITHOUT WELL

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
28	0 - 2 pCi/L	10	36	36	3.42	2.33	14.86
	2 - 4	15	54	89			
	4 - 16	3	11	100			
	OVER 16	0	0	100	PCNT > 4.0 pCi/L = 11		

DATA RANGE : HOUSES UNDER 1000 SQ.FT. - WITH WELL

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
7	0 - 2 pCi/L	3	43	43	3.51	2.59	8.86
	2 - 4	2	29	71			
	4 - 16	2	29	100			
	OVER 16	0	0	100	PCNT > 4.0 pCi/L = 29		

DATA RANGE : HOUSES BETWEEN 1000 AND 2000 SQ.FT. - WITH WELL

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
65	0 - 2 pCi/L	19	29	29	6.46	3.53	45.58
	2 - 4	15	23	52			
	4 - 16	26	40	92			
	OVER 16	5	8	100	PCNT > 4.0 pCi/L = 48		

DATA RANGE : HOUSES OVER 2000 SQ.FT. - WITH WELL

No. OF PACKETS	RADON LEVEL	#	%	CUM %	AVG.	MEDIAN	MAX.
19	0 - 2 pCi/L	1	5	5	8.88	3.48	30.00
	2 - 4	10	53	58			
	4 - 16	4	21	79			
	OVER 16	4	21	100	PCNT > 4.0 pCi/L = 42		

It should be noted that homes that are in a hot humid climate where air conditioning is the rule in the summer, have the same closed conditions year around and there may be little difference on a seasonal basis. In New Brunswick, in general, summer days are very pleasant, homes are generally open, windows open, doors open with screen doors present. Rarely are the days so hot that homes are kept closed up. Very few homes are air conditioned. Many do have a basement humidity problem.

The most important variable seems to be the presence or absence of a private well as the water supply. The median value for all houses with a well is 3.45 pCi/L versus only 2.25 pCi/L for those homes without wells. It is interesting, too, that no home without a well had a radon level higher than 16 pCi/L, whereas all 9 values above that were in homes with wells.

TABLE 3

Comparison of Fall and Winter Radon Levels in 50 Fredericton Area Homes - 1987

Average Ratio Winter/Fall ("B"/"A" Packets)	1.3
Maximum Ratio "B"/"A"	4.1
Minimum Ratio "B"/"A"	0.4
Median Fall Radon Level ("A" Packets)	3.20pCi/L
Median Winter Radon Level ("B" Packets)	3.91pCi/L

NOTE: Radon levels determined using 3 day exposures in basements of 40 gram charcoal packets installed by homeowners and received and returned for evaluation by mail.

The above comments do not at all mean that the radon is entering the home in the well water. This is a problem in the nearby State of Maine in a number of houses, especially in those houses where the well radon levels are extreme. To date the highest value well in the world has been found in Maine with the value of 1.5 million pCi/L of water. As an indication of the uncertainty in radon levels and the difficulty of generalization in a particular area, a well only 50 yards away has only 15,000 pCi/L. There was a wide spread in the water radon values measured in the Fredericton area. These are tabulated in Table 3. Only 3 samples tested (vials 8, 13 and 37) provided high radon levels. The distinction between with and without a well clearly relates to whether the home is in the city or in the country. One of the difficulties as noted above with regard to the Cross-Canada survey done by Health and Welfare Canada in the 1970's was that essentially all homes measured were in cities. Presumably none of those homes were in the country and had private wells as the water supply.

The other variables such as relative number of air changes per hour as noted as perhaps inferable from whether the insulation level was low, medium or very heavy, are of course confounded by whether or not the homes in question do or do not have wells. Other variables of interest are the age, the size and the type of heating system.

A field trip was also taken to four homes with relatively high radon concentrations in a suburban area. In each case the house used wood as the major heating fuel with a backup system of either an electric or oil fired furnace. None of these homes had a separate air supply for the wood burning furnace. Therefore, one would expect a strong stack effect pressure differential between the basement and the upstairs which would be very important in sucking in soil gas. Three of these four homes with high radon concentrations were 170 years, 140 years, and 80 years old respectively. All had rock walls 3' to 4' thick with some mortar. Clearly the walls were "porous" to soil gas. All had poured concrete floors in the basement. One floor was a mix of poured concrete and dirt. Two of these high value homes were on large deposits of excellent gravel, therefore providing an easy path for soil gas migration from a large distance as opposed to what one would find in an adjacent clay or generally rocky area. One home was sitting on solid rock. Their well went down 250' and it was rock all the way down. This means that there was rock probably sandstone or granite in large quantities close to the home. This in itself would not necessarily produce high radon values, since a key factor is how much surface area there is per unit mass of rock. If rock had to be blasted to prepare the space for the foundation, then presumably this would induce a great deal of fragmentation and fracturing in surrounding rock. In turn this would produce a high surface area and relatively easy access of the radon produced in the rock particles to the exterior soil gas or water going by.

Bernard Cohen has also found that values were highest in the country, less high in the suburbs and lowest in city areas. This is perhaps not surprising as it is rare indeed that mines are located in cities.

Within the City of Fredericton there was an instance of two houses next door to each other with one being 3 times higher than the other. In another instance a relatively high value was apparently produced by the fact that there was so much rock in the basement area that some of it was still there with poured concrete around it, thus giving direct access from the rock actually within the house. It would appear that the actual individual house's situation on its lot with regard to preparation for foundation construction is as important as the amount of uranium in the area, again accentuating the difficulty in predicting radon levels even in a local neighbourhood, no less an area.

Sampling Techniques

Prior to providing any charcoal packets several different techniques were evaluated for the selection of the test homes. It was desirable to cover the Greater Fredericton area as opposed to just the City itself. Furthermore it was hoped that there would be a representative sample. Technically this would mean that every home in the area had an equal chance of being selected. Another possibility would be to use the employees of a particular institution in town such as the New Brunswick Electric Power Company, the University of New Brunswick, the Provincial Government. This might select homes in certain areas by virtue of the cost of the homes. Well paid people presumably are more likely to live in an expensive neighbourhood which might destroy the notion of random sampling for the whole area. In addition it is not known what influences a person to respond to a request for participation even at no cost in a test program. General discussions with many people in the community indicated that most people were not aware of the radon problem or, if aware, were not much concerned. The concern is important because presumably if one was concerned about radon in one's neighbourhood one is more likely to participate in a volunteer random sampling.

Conversely if one were interested in selling one's house, it is conceivable that the owner might not want to have his house tested. Similar problems of course are being met with those trying to test the population for exposure to the AIDS virus.

Clearly if one is concerned about nonconfidentiality of information and is concerned that one might indeed have been exposed to the AIDS virus, one is less likely to participate in a large scale survey as opposed to an anonymous test, if there is such a thing. In any event the final technique selected for the program as reviewed and approved by the project manager was the use of the property tax rolls for Fredericton and adjacent areas. These are on a computer printout and in a roughly random fashion. The first owner occupied home was selected from every fifth page of the various taxing bodies in the area. A letter was sent with a self-addressed stamped envelope to 476 homeowners asking for people to participate in the program at no cost to themselves. Approximately 140 owners responded. A few additional persons were selected randomly because of the failure of some people to follow-up with return of either the initial request form or the sample after it was sent to them.

During the course of the program there was some publicity given to the radon problem. Two different television programs; one from the Maine Public Broadcasting Network, and one from CBC, were broadcast. In addition there was a series of articles in the Globe and Mail some of which were read by some people in the community. The Fredericton Daily Gleaner and Saint John Telegraph Journal which are the two major newspapers in the Fredericton area carried essentially nothing about radon and certainly no major

articles during the course of the survey which would encourage people to get a free test result.

There were no difficulties with regard to the shipments of the packets themselves other than the mail strike early on. That is to say local mail service normally assured that the packets were received within 2, 3 or 4 days of when their exposure was terminated. Discussions were held with post office personnel to reassure about safety. There were no penetrations of the packets leading to the spillage of charcoal. There were no values measured within the city of Fredericton proper that were above 16 pCi/L. All the values higher than that were measured in the areas surrounding Fredericton which had not been previously investigated during the testing of the late 1970's.

Occasionally someone would forget to indicate a date or a time or both. These were required in order to correct for decay time and exposure time for the charcoal. Usually this information could then be obtained by telephone.

In all instances the individuals were eventually notified of their test results by mail. For those who had exposed the charcoal in the early fall, the measurement was only given after the fall and winter measurements had been completed. This saved on postage and also it was felt that some people getting a low value might not be interested in testing again. By encouraging them to submit the second sample before the first test result was made available to them, it was felt they would be more likely to be co-operative. There were a few people who did not return test

packets so far as is known. No major effort was made to solicit their co-operation. The test result notification form is shown in Appendix 3.

Water Radon Levels

It was a requirement that approximately 50 well water samples be tested for radon levels. In the past in the area the only way in which this test could be conducted would be for a well trained radiation protection person to personally visit the home and extract a sample. This is a very time consuming procedure and the techniques used to evaluate the radon level in the water were not terribly precise or sensitive. Instead a technique was developed that could be used in the future to do mail order testing of radon levels similar to that used with the charcoal packets (where people throughout the province or throughout the country could submit their water samples to a central laboratory). The technique developed is very similar to that used by the State of Maine at their primary Health Services Testing Laboratory in Augusta. A visit was made to that laboratory as a follow up to a visit made over a year previous. Several phone conversations were held as well. Details are given in Appendix 4.

The results of the water tests are summarized in Table 4, in pCi/L of water. Considering that the highest level ever measured in the world is 1.5 million pCi/L (in Maine) it is seen that even the highest test results are not very close to the maximum value. Considering the size of the sample of less than 50 homes and that the highest level values were all measured in the Harvey area previously known to have high levels the results are not particularly surprising.

It is interesting to note that the three homes (samples 8, 13, 37) with the highest values of radon in the water did not have truly excessive levels of radon in the home, having respectively 9.4, 8.8, 8.5 pCi/L. It would appear that most of the radon in Fredericton area houses is entering the homes through the basement from the surrounding soil rather than being released into the homes as a result of turning on the well water supply. Obviously there may be many areas in the province in which there are individual or even groups of homes in which the radon level in the water is even higher than that measured and which could release, at least during and shortly after the time when the faucets are open. This remains to be seen. But with the new technique it is clearly possible to evaluate numerous water samples submitted by mail at relatively low cost because the amount of water required is only in the order of 20 ml.

Table 4

Radon Levels in Fredericton Area Wells

Vial No.	PicoCuries/litre	Vial	PicoCuries/litre
1	1688	25	3586
2	1950	26	2417
3	862	27	16
8	30285	28	907
10	1895	30	1212
12	1185	31	940
13	33907	33	4290
14	350	34	697
15	570	35	1072
16	816	37	11319
17	4993	38	1594
18	1076	39	1345
19	499	40	1792
20	295	41	314
21	1759	44	2339
22	1387	45	521
23	904	46	1387
24	505	48	3276

SUMMARY of Above	Fredericton %	Maine %*
Less than 2000 pCi/L	75	36.8
2,000 - 10,000	16.7	39.5
10,000 - 20,000	2.8	11.1
20,000 - 50,000	5.6	9.1
Over 50,000	0	3.5
Mean = 1274 pCi/L		

* E. Moreau, Private Communication, December 8, 1987, 4560 wells

High Level Home

It should be noted that in the course of this testing program a set of measurements were made on a commercial basis in a town about 50 miles from Fredericton in a country home, more than 100 years old. The Owners had requested a measurement on the basis of a popular magazine article. It was found that the level in the basement was 90 pCi/l. This caused great distress to the individual and his wife who was expecting a baby at the time. The test results were confirmed with an in-home visit in conjunction with Keith Davies, the Radiation Protection Officer of New Brunswick. It was also determined that the home's well water did NOT have high radon concentration. The reasons for the high values seemed to be fairly straight forward.

1. There was no concrete basement floor.
2. The house sat on a huge quantity of gravel just a few feet beneath the ground thus making it very easy for radon to reach the house.
3. The primary heating system involved the use of wood in a main floor furnace which did not have a separate air supply and therefore certainly contributed to sucking soil gas out of the ground beneath the house.
4. The house had been greatly tightened by the replacement of old windows and doors, with new ones; by the addition of a great deal of insulation and vapour barriers. Heating costs had indeed been reduced but a situation was created in which the radon levels were undoubtedly higher than was either desired or necessary.

The point here is that this is one isolated house - nobody had previously measured radon level that high in New Brunswick. The people were concerned. Their concern was not at all with the real estate value but rather with the potential health effects to them and their soon-to-be-born child. In cities; however, one might expect that the concern would be quite different as was clearly demonstrated with regard to the UFFI problem of several years ago. It is well known that many of the homes from which UFFI was removed had no health problems whatsoever. But with lending institutions requiring that a UFFI presence statement be made by the seller and in many instances not providing loans for the purchase of homes with UFFI still in them, it was deemed necessary by many people to have the UFFI removed. This reaction is understandable. A similar approach to radon and a demand by the public that the government get involved in removal could be an enormously expensive procedure.

There are companies in the United States now offering radon measurements for approximately $12 U.S. per home covering all costs. It is clear that charcoal in flat packets can be mailed very inexpensively in Canada - 74¢ each way. A major difficulty from a cost viewpoint of the use of the canisters is that because their thickness exceeds the guidelines provided by Canada Post, the minimum mailing cost is $2.40 each way.

Maine Contacts

The neighboring State of Maine has officially been aware of a potential residential radon problem for a number of years as a result of extensive research carried out at the University of Maine in Orono and by the State Health and Human Services Department in Augusta. Maine's geology, climate and mode of home construction are fairly similar to those of New Brunswick. Initial contact was made between the Principle Investigator and Eugene Moreau, Maine Health Physicist at an EPA training seminar in Woburn, Massachusetts in 1986. Mr. Moreau offered to assist in any way possible. The Principle Investigator also participated in a seminar held at the University of Southern Maine just after which he made his first visit to the Maine Laboratory which is under the direction of Cheryl Baker. She has also been most helpful.

The State of Maine has been offering mail order home radon testing for a few years on a fee-for-services basis. Ms. Baker has manufactured about 200 reuseable charcoal canisters very similar to those employed by Dr. Bernard Cohen of the University of Pittsburgh. The charge has been about $20-22 per home measurement, with the canisters left in place for one week, usually in the winter, and counted using equipment already available at the State Laboratory. The presence of the Maine Yankee Nuclear Powerplant which has been in operation for many years has led to a

requirement for environmental testing for radioactivity. In addition, Ms. Baker has also established a well water testing capability using mail order sampling and liquid scintillation techniques since Maine seems to have some of the highest radon-in-water levels of any area. Dr. Jerry Lowry at the University of Maine has been a leader in research associated with the mitigation of these high water levels including the development of the use of tanks of granular activated charcoal as a means for greatly reducing the amount of radon transferred from the well water into the homes. As noted elsewhere in this report, the highest water radon level ever located world wide was in a well in Leeds, Maine, which tested out to an incredible 1.5 million pCi/L. Less than 100 yards away was another well having only 1.00% as much radon.

Ms. Baker has constructed a radon test chamber from an old oven. The radon level is both controlled and monitored using Canadian Pylon equipment. She was kind enough to expose a number of the AirChek charcoal radon test packets identical to those used during this research program to provide a calibration for the present series of measurements. In addition she has succesfully participated in the EPA Test Protocol radon technique evaluation program.

During more than 2 years of sample testing Ms. Baker had evaluated many different aspects of her testing procedures. For example, a major concern of water sample collection had been whether or not a trained person using a syringe would be required which would make such testing very expensive. As it turns out a carefully drawn sample filling the sample bottle is quite satisfactory especially in view of the considerable variation in radon values for a given well. Thus sending the full 20 ml vial in a cardboard box as soon as possible after withdrawal, making sure that the pump has been running long enought to empty any storage tank, is quite a suitable procedure.

She also determined by measuring gamma ray spectrum for each sample for a long time that none of the charcoal canisters contained other radioactive contaminants than the radon daughters. Also of significance were a series of measurements as a function of time after charcoal exposure and after water sample collection to ensure that the half life of the measured radioactive decay followed that of radon. This established that there was no loss of radon while the canister or water sample was in transit or waiting for readout.

Ms. Baker was also able to show with regard to the liquid scintillation testing of the well water samples that the scintillation cocktail can be added in the lab just prior to automated analysis rather than being added to the sample in the field. She performs annual calibrations of her liquid scintillation system. This procedure involves the use of various dilutions of a NBS

standard Radium solution allowed to stand for three weeks to allow the radon to come to equilibrium. Monthly she runs a sample through. Calibration, even over a dilution range of more than a factor of 200, has varied by less than 2% over the years.

The Augusta lab in many ways provides a prototype for emulation by any province interested in providing services (at cost roughly speaking) to local citizens concerned with home radon and well level determinations. All samples pass through the mail. The public pays for all testing. Equipment purchased for other purposes is employed. Skilled professionals are, in general, not involved in house calls. The test methods provide information that is quite accurate for screening purposes at prices that do not seem burdensome and without straining the budgets of either the home owners or the government. They do not make a great effort to advertise their services. It should be noted that the primary barrier to using the Maine Lab's services for Canadians is simply the long time it takes for First Class mail between New Brunswick and adjacent Maine. Typical mail delivery times are 8-10 days between places less than 200 miles apart!

Other Professional Contacts

The Principal Investigator made numerous contacts with other researchers by phone and mail and at conferences at the University of Southern Maine and especially the 2nd International Conference on Radon held at Cherry Hill, New Jersey, under the auspices of the Air Pollution Control Association. Some of the organizations contacted included the EPA, The Research Triangle Institute, the University of California, The Bonneville Power Administration, the Oak Ridge National Laboratory, various members of the Health Physics Society, university professors, researchers in Sweden, England, Switzerland, etc. as well as various geologists, health physicists, epidemiologists, etc. Conference and published papers were provided by many individuals including persons associated with Health and Welfare Canada and other members of the American Association of Radon Scientists and Technologists.

There has been an exponential growth of both public and private involvement in testing for and mitigating radon outside Canada and many, many conferences have recently been or are soon to be held. It is easy to become rapidly out of date with the latest activities if one does not follow the literature closely.

Predictability of Home Radon Levels

There has been considerable effort applied particularly by some of the National Labs in the United States and by such researchers as geologist Douglas Mose of George Mason University to evaluate all the factors that determine the radon level in a particular home. There are complicated methods available for measuring the radium concentration in the rock and soil near a home, the radon emanation from that soil, the flow of soil gas into the home, and other variables. Unfortunately these measurements are expensive and have not yet been shown to provide an accurate method for predicting home radon levels. It is far cheaper and quicker and requires much less professional effort to expose a charcoal packet or canister (purchased at a hardware store or sent through the mail) with centralized analysis in a laboratory at a nominal cost and with results available within a week or 2 of the sample exposure for 2 - 4 days.

The air survey for uranium, which has been conducted in many areas of Canada, might possibly be useful as a preliminary tool for estimating areas wherein one might expect to find higher than average radon levels, if the flights are conducted in closely arrayed paths. Even then predicatability for individual homes has eluded researchers.

On a practical level the radon situation might be compared to the termite problem in many warmer areas of the United States. Most home purchase agreements provide for a termite inspection and for a financial agreement as to how payment will be made for the

work required to eliminate the problem. Theoretical techniques for estimation of which homes might have a termite problem might be of interest to researchers. From a practical viewpoint, inspection and mitigation are procedures which are sufficiently simple and straightforward and inexpensive from the buyer and seller viewpoints as to be far more appropriate than government sponsored theoretical approaches. There is general agreement within the large and still growing private radon monitoring and mitigation community in the U.S. that mail order testing works and that mitigation can be done for less than about $1,000 per home for essentially all homes even those having radon levels exceeding 2,000 pCi/L, if advantage is taken of all that has been learned during the last 5 years. There is no reason to expect that the provate industry of Canada cannot do as well.

Conclusions

1. The use of paper, charcoal packets sent and received by mail and kept in situ for a few days is an effective, inexpensive, relatively simple and straight forward technique for screening homes for radon.
2. A very substantial amount of experience and relevant technology has developed in the last five years with regard to evaluation of home radon levels, determination of methods for mitigation of high levels and an understanding of the important variables that determine radon levels.
3. The measurements made in the Fredericton area lead to a number of conclusions consistent with those reached by other researchers elsewhere:
   (a) Levels are higher in the country than in the city
   (b) For the same homes, winter measurements are on the average approximately 30% greater than summer measurements
   (c) The range of radon levels varied by more than a factor of 50.
   (d) The range of radon levels in the water in wells in the Fredericton area covered at least a factor of 50 but all values were at least 40 times lower than the maximum ever recorded.
4. The percentage of homes in the Fredericton area found to have radon levels above 2 pCi/L, 4 pCi/L and 20 pCi/L is very much greater (66%, 30%, 3.5%) than was determined in the pre 1980 Canadian Cross Country Survey using summertime, daytime, grab

sample measurements (21.5%, 6.8%, 0% respectively). These measurements indicated that the overall median radon level for the Fredericton area is 2.7 pCi/L as compared with the grab sample summertime median of only 0.66 pCi/L.

5. Neither the public in general nor the media are well educated about radon. They have concerns about many other environmental hazards such as pesticides, herbicides, asbestos, etc. which, judging by all the recent research, provide a very much smaller risk to the population than does radon. Thus, there seems to be a very strong need for public education.
6. Discussions with many homeowners on a private level indicated that people would be quite willing and able to pay a modest fee (perhaps under $30.00) to determine the radon level in their homes.
7. There seems to be no reason for even suggesting that the federal or provincial government somehow has a responsibility for monitoring or mitigating high radon levels in private homes in Canada though there would be a government role with regard to schools and other government owned facilities.
8. Discussions with many researchers across the continent indicate that mitigation techniques are far better developed now than they were a decade ago and that costs for do-it-yourselfers would be under $500 and that even having commercial firms doing the work, the costs should still be under $1,000.

9. No single conversion factor is available as a technique for converting a 2 - 4 day basement charcoal measurement to an annual average. Such a factor will undoubtedly vary from area to area and even from year to year. However, these measurements do provide an excellent guide as to homes that are likely to have high risk levels associated with radon.

10. No technique exists for the accurate prediction of radon levels in a home based either on the characteristics of the home, the uranium content or the permeability of the soil or the levels in neighbouring homes.

B I B L I O G R A P H Y

"Evaluation of Occupational and Environmental Exposures to Radon and Radon Daughters in the United States", NCRP and Measurements Report 78, May 31, 1984, 204 pages, 296 Ref.

"Exposure to Enhanced Natural Radiation and Its Regulatory Implications" Proc. of a Seminar Held in Maastrict, The Netherlands, 25-27 March, 1985. SPECIAL ISSUE of the Science of the Total Environment, Vol. 45, 1985, 80 papers, 701 p.

"Human Exposure to Radon Decay Products" ATOM 352, Feb. 1986, pp. 2-6, 13 Ref.

"Indoor Radon" Proc. of an APCA International Specialty Conference, Philadelphia, Pannsylvania, February, 1986, 252 p. from APCA.

"Metrology and Monitoring of Radon, Thoron, and Their Daughter Products" Report by a Group of Experts of the NEA OECD, Jan., 1985. ISBN 92-64-12767-4, 148 p., 169 Ref.

"Proceedings of 3rd International Conference on Indoor Air Quality and Climate" Stockholm, August 20-24, 1984, sponsored by WHO, 2 Vol. At least 23 papers on radon in Vol. 2. "Radon, Passive Smoking, Particulates and Housing Epidemiology".

"Radionuclide Release into the Environment: Assessment of Doses to Man" ICRP Publication 29, Pergamon Press (Annals of the ICRP 2:2 1979), 72 p., 62 Ref.

"Radon Protection and Health Effects", Committee on Interagency Radiation Research and Policy Coordination, Science Panel Report No. 4, Office of Science and Technology Policy, Executive Office of the President, August 1986, 15 p., 15 Ref.

"Radon Gas: A Deadly Threat", Newsweek, August 18, 1986 pp. 60-61.

"Radon/Radon Progeny Measurement Proficiency Program: Cumulative Proficiency Report" July 1987, EPA 520/1-87-015, USEPA, Office of Radiation Programs, Washington, DC 20460 (Prepared by Research Triangle Inst., Radon Tech. Info. Service), 47 pages.

Alter, H. W., and Oswald, R. A. "Nationwide Distribution of Indoor Radon Measurements: a Preliminary Data Base:, JAPCA, March 1987, Vol. 37:3, pp. 227-231, 23 Ref., 4 Tables, 1 Fig.

Backgrounder, "Understanding Indoor Radon", Bonneville Power Administration, June 1987, 15 p., 19 Fig.

Baechler, M. C., "Summary of Indoor Air Quality Research Projects at Bonneville Power Administration:, Oct. 1985, 22 p., 29 projects.

Bonneville Power Administration, Radon Monitoring Results from BPA's Residential Weatherization Program, Report No. 8 April 1988, 16 pages.

Brambley, M. R. and Gorfien, M., "Radon and Lung Cancer: Incremental Risks Associated With Residential Weatherization" Energy Vol. 11, No. 6, pp. 589-605, 1986, 49 Ref., 6 Tables, 5 Figs.

Bramwell, J. B., "Radon: The Uninvited Guest" CMAJ, Vol. 134, April 1, 1986, pp. 713-714.

Canadian Public Health Assoc. Task Force on Fluoride, Long Harbour, NFLD., 1978, Appendix F, "Radiation Survey of Long Harbour, Newfoundland", 20 p., 3 Fig., 3 Tables, 9 Ref.

Carriere, P. E., and Legare, J. M. "Radon and Radon Daughters in Homes of Radioactive Anomalies of Quebec - One Year Study", in Supplement to the Proc. of the Second APCA International Specialty Conf. INDOOR RADON II, Cherry Hill, N.J., April 1987, pp. 41-58, 10 Fig., 6 Ref., 1 Table.

Chandra, J. J. "Ground Investigation of Airborne Gamma ray Radiometric Anomalies in New Brunswick by Truck-Mounted and Hand-Held Gamma Ray Sensors" MSc Thesis, Dept. of Geology, Univ. of New Brunswick, Feb. 1981, 221 p., 59 Fig., 39 Tables, 12 Plates, 36 Ref.

Clemente, G. F., Eriskat, H., O'Riordon, M. C. and Sinnaeve, J. "Indoor Exposure to Natural Radiation and Associated Risk Assessment" Radiation Protection Dosimetry, Proc. of and Intern. Seminar held at Anacapri (Italy) Oct. 3-5 1983, CONF. 831049, 7:1-4, 1984, 87 papers, 440 p.

Cohen, B. L., "Variation of Radon Levels With Season, Room Type, House Characteristics, and Socioeconomic Factors", 14 p., 3 Figs., 17 Tables, 1987.

Cohen, B. L., Gromicko, N. "Variation of Radon Levels in U.S. Homes with Various Factors", J. Air Pollution Control Association, Feb. 1988, Vol. 38:2, pp. 129-134, 3 Fig., 11 Tables.

Cohen, W. Senator, "Radon is Another Example of the Danger Within", Houlton, Maine, Pioneer Times, Sept. 10, 1986.

Costic, E. N., "Le radon dans les habitations, un constat" Promoclim E, Tome 16, No. 6, Nov. 1985, pp. 345-354, 11 Fig.

Cothern, C. R., Smith, J. E., ENVIRONMENTAL RADON, 378 p., 1987, $55.00 Plenum Press, NY. Vol. 35 in the series Environmental Science Research.

DSMA ATCON LTD., "A Computer Study of Soil Gas Movement into Buildings", March 5, 1985, Report No. 1389/1333, 22 p., 11 Fig., 1 Table, 1 Ref.

DSMA ATCON LTD., "Effect of Radon Collection-Rate Fluctuations on the Precision of Radon and Thoron Daughter Concentration Estimates", August 31, 1984, Report No. 1326/1293, 22 p., 1 Fig., 11 Tables, 10 Ref.

Dumont, R. S. and Fingley, D. A. "Control of Radon in Houses" CANADIAN BUILDING DIGEST, February 1988, CBD 247, Published by Institute for Research in Construction, National Research Council of Canada, Ottawa, 4 pages.

Eaton, R. S., Scott, A. G.; "Understanding Radon Transport into Houses", Radiation Protection Dosimetry 1983, Vol. 7, No. 1-4, pp. 251-253, 1 Table, 1 Ref.

Eaton, R. S., "The Past, Present and Future of the Canadian Radon Standard or How We Try to Tame Nature", Proc. of Intern. Specialty Conf., "Indoor Radon", APCA, SP-54, Philadelphia, PA., Feb. 1986, pp 63-69, 1 Table, 9 Ref.

Eaton, R., "Case-Control Study II Canadian Studies of Lung Cancer and Radon", June 1986, Radon and Lung Cancer Workshop, U. of Pittsburgh, 7 p., 1 Table.

Edling, C., Wingren, G., and Axelson, O., "Quantification of the Lung Cancer Risk from Radon Daughter Exposure in Dwellings - An Epidemiological Apporach" Environment International, Vol. 12, 1986, 6 pages, 4 Tables, 32 Ref.

Edling, C., Ling, H., Axelson, O., "Radon in Homes - A Possible Cause of Lung Cancer", 1982 (Dept. of Medicine Occupational, Univ. Hosp., Linkoping, Sweden), 1982, 26 p., 41 Ref., 5 Tables, 1 Fig.

Edling, C., "Lung Cancer and Smoking in a Group of Iron Ore Miners" American Journal of Industrial Medicine 3"191-199 (1982), 4 Tables, 35 Ref.

Edling, C., and Axelson, O., "Quantitative Aspects of Radon Daughter Exposure and Lung Cancer in Underground Miners" paper, 23 p., 1982, 4 Tables, 1 Fig., 19 Ref.

Edling, C., Comba, P., Axelson, O., Flodin, U., "Effects of Low-Dose Radiation - A Correlation Study" Scand. J. Envirn. Health 8 (1982) Suppl 1, 59-64, 2 Tables, 31 Ref.

Eheman, C. R. and Schock, J. P., "Results from Indoor Radon Sampling Program in National Park Service Buildings" paper presented at Health Physics Society Meeting, Boston, July 1988, 13 p., 7 Tables.

EPA Reducing Radon in Structures: Training for Radon Diagnosis and Mitigation Student Manual, Prepared for the Office of Radiation Programs.

EPA Reducing Radon in Structures: Training for Radon Diagnosis and Mitigation Instructor Guide, Prepared for the office of Radiation Programs.

EPA Journal, Vol. 12, Number 6, August 1986, 8 articles on Radon.

EPA, "Radon Reduction Methods: A Homeowner's Guide", August 1986, 24 p.

EPA, "A Citizen's Guide to Radon: What it is and What to do about it", August 1986, 14 p.

Ericson, S. O., Schmied, H. "The First Long Time Comparison of Techniques for Passive Integrated Measurement of Radon and Radon Daughter Concentration Performed in an Occupied Dwelling" The Science of the Total Environment 45 (1985) pp. 405-415, 2 Tables, 5 Fig., 2 Ref.

Ficner, C., Riley M., Lubun, M., "Improving Air Quality Through Energy Conservation Programs" pp. 534-548, Transactions APCA, Ibid.

George, A. C. "Instruments and Methods for Measuring Indoor Radon and Radon Progeny Concentrations" in Indoor Radon Proc. of an APCA International Specialty Conf., Philadelphia, PA, February 1986, pp 87-100, 3 Tables, 36 Ref.

George, A. C., and Hinchliffe, L. T. "Measurements of Radon Concentration in Residential Buildings in the Eastern United States", Chapter 4, Radon and Its Decay Products, Occurence, Properties and Health Effects,, American Chemical Society Meeting J. April 1986, New York City, ACS Symposium Series 331, 1987, Ed. by Philip K. Hopke, 609 pages, pp. 42-62, 12 Ref., 4 Fig., 9 Tables.

Gray, J., Windham, T., "EERF Standard Operating Procedures for Radon-222 Measurement Using Charcoal Canisters:, March 1987, EPA 520/5-87-005. (Eastern Environmental Radiation Facility, Montgomery, AL, 36109, 30 p., 7 Ref., 7 Fig., 1 Table.

Green, L. "Radon: A Threat You Can Deal With" HOME MECHANIX, June 1988, 84:722, pp. 83 et seq. 28 Fig., (Many in Colour).

Gustafson, J., Hildingson, O. "Radon Measurements in Dwellings Using Activated Charcoal" Radiation Protection Dosimetry, 7:1-4, 1984, pp 203-206, 7 Fig., 2 Tables, 4 Ref.

Hamilton, J., "Radon Gas: An Invisible Health Risk" Protect Yourself July, 1987, pp. 7-13.

Hanley, R., "Radon: For the Homeowner, Some Questions and Answers" NY TIMES, Jan. 1, 1987.

Hawthorne, A. "Radon Levels and Home Energy Conservation" OAK RIDGE NAT. LAB. REVIEW, Vol. 20:3, 1987, pp. 55-61, 9 Fig.

Health Risks of Radon and Other Internally Deposited Alpha Emitters, BEIR IV Committee on the BEIR, Board on Radiation Effects Research, Commission on Life Sciences, National Research Council, National Academy Press, Washington DC, 1988, 618 p., 8 chapters, 8 appendices, 91 principal tables, 815 Ref.

Hess, C. T., Weiffenbach, C. V., and Norton, S. A. "Variations of Airborne and Waterborne Rn-222 in Houses in Maine", Environment International, 1982, No. 8 pp. 59-66.

"Indoor Air Quality Environmental Information Handbook: Radon" January 1986, Prepared for U.S. Department of Energy by Mueller Assoicates, DOE/PE/72013-2, 269 p., 55 Tables, 67 Fig., 273 Ref. from National Technical Information Services, Springfield, VA $22.95 (+$3 Postage).

Kerr, R. "Indoor Radon: The Deadliest Pollutant" SCIENCE Vol. 240:29, April 1988, pp. 606-608, 4 Ref.

Lafavore, M., "RADON: The Invisible Threat", What it is, Where it is, How to Keep Your House Safe, Rodale Press, Emmaus, PA, 1987, 256 p., 19 Ref.

Lane, C. A., Armstrong, J., Lind. J., and Woods, J. E. Jr., "Cooperative Indoor Air Quality Research Between Government and Industry - A Minnesota Case Study" pp. 574-583, Trans. APCA, Ibid.

Letourneau, E. G.; McGregor, R. G.; Taniguchi, H.; "Background Levels of Radon and Radon Daughters in Canadian Homes", Proc. of the Specialist Meeting on Personal Dosimetry and Area Monitoring Suitable for Radon and Daughter Products, Paris, Nov. 20-22, 1978, 167-185, NEA' OECD, 6 Tables, 10 Fig., 4 Ref.

Letourneau, E. G., McGregor, R. G.; Walker, W. B.; "Design and Interpretation of Large Surveys for Indoor Exposure to Radon Daughters", Radiation Protection Dosimetry, Vol. 7 No. 1-4, 1983, pp. 303-308.

Letourneau, E. G., "Limitation of Exposure to Natural Radioactivity in Canada", The Science of the Total Environment 45 (1985) 647-656, 11 Tables, 6 Ref.

Letourneau, E. G., Wigle, D. T.; "Mortality and Indoor Radon Daughter Concentrations in 13 Canadian Cities", Presented at Specialist Meeting on the Assessment of Radon and Daughter Exposure and Related Biological Effects. CNEN, CSN CASACCIA, 307 March 1980, Rome, Italy; 8 p., 2 Tables, 4 Figures, 6 Ref.

Letourneau, E. G., "A Radon Standard for Canada", Trans. of "Indoor Air Quality in Cold Climates: Hazards and Abatement Measures", D. S. Walkinshaw, Ed., APCA, 1985, pp. 488-495, 10 Tables, 6 Ref.

Love, R. L., "Bonneville Power Administration's Risk Management Strategy for Mitigation Indoor Air Quality Effects in its Home Weatherization Program", pp. 549-560, 9 Ref., Trans. APCA, Ibid.

Lowry, J. D. "Radon at Home" CIVIL ENGINEERING, February 1987, pp. 44-47.

Lowry, J. D., Brandow, J. E., "Removal of Radon from Water Supplies", Journal of Environmental Engineering (ASCE) III:4, August, 1985, pp. 511-527, 13 Fig., 2 Tables, 36 Ref.

Makofske, W. J., and Edelstein, M. R., Radon and the Environment: Conference Proceedings, Conf. held at Ramapo College of New Jersey, May 8-10, 1986 A Publication of the Institute for Environmental Studies School of Theoretical and Applied Science Ramapo College of New Jersey, Copyright 1987, 60 papers, 473 p., 8 sections, 6 Appendices.

Mayhew, W., "The Question of Radon: Is it a Concern in Your Part of Canada?" Habitat 2000, Summer 1986, p. 17, 18, 55.

McBride, J. L. and Davies, K. L. "Natural Radioactivity Measurements for the Harvey Area, York County, New Brunswick" (Report of the N.B. Department of Health, Radiation Protection Services) August 1981, 26 p., 8 fig., 4 Tables, 18 Ref.

McCullough, R. S., Letourneau, E. G.; Waight, P. J.; "A Four Factor Model for Estimating Human Radiation Exposure to Radon Daughters in the Home", Health Physics Vol. 4, March 1981, pp. 299-305, 5 Tables.

McGregor, R. G., Gourgon, L. A., "Radon and Radon Daughters in Homes Utilizing Deep Well Water Supplies, Halifax County, Nova Scotia", J. Environ. Sci. Health, A15(1), 25-35 (1980), 4 Tables, 8 Ref.

McGregor, R. G., Vasudev, P.; Letourneau, E. G.; McCullough, R.S.; Prantl, F. A. and Taniguchi, H.; "Background Concentrations of Radon and Radon Daughters in Canadian Homes", Health Physics Vol. 39 (August) 1980, pp. 285-289, 3 Tables, 7 Ref.

McGregor, R. G., "Working Paper on Environmental Radon and Radon Daughter Concentrations Federal-Provincial Sub-Committee on Radiation Surveillance", May 6-7, 1980, 35 p., 9 Tables, 3 Fig., 44 Ref.

McGregor, R. G., "Radon in the Homes Environment", Presented at the 71st Annual Conference Canadian Public Health Assoc., Ottawa, Ontario, June 23-26, 1980, 11 p., 1 Table, 2 Fig., 7 Ref.

McGregor, R. G., Walker, W. B.; Letourneau, E. G., "Radon and Radon Daughter Levels in Energy Efficient Housing", The Science of the Total Environment, 45 (1985) 271-278, 9 Ref., 4 Tables, 2 Fig.

McGregor, R. G.; Walker, W. B. and Eaton, R. S., "Experiences in the Development of a CR-39 Alpha Track Dosemeter for Radon", Presented at "Indoor Radon II" Specialty Conference, APCA, Cherry Hill, NJ, April 6-10, 1987, 7 p., 7 Ref., 3 Fig.

Mitchell, G., U.S. Senator, "Radon Gas: An Invisible Enemy" Presque Isle, Maine, Star Herald, August 13, 1986.

Monastersky, R., "Lung Cancer Risks from Radon Exposure" SCIENCE NEWS, January 16, 1988, p. 39.

Mose, D., Progress Report to Participants in the GMU Radon Study, April 25, 1988, 16 p., 23 Fig.

Mose, D. G., and Mushrush, G. W. "Development of Radon Problem Area Maps in Virginia and Maryland", Health Physics Society Annual Meeting, Boston, Mass, July 4-8, 1988.

Mose, D. G., and Mushrush, G. W., "Uncertainties for Radon Monitors: Single Measurements vs Annual Measurements", The 1988 Symposium on Radon and Radon Reduction Technology, Denver, Oct. 18-21, 1988.

Mose, D., and Mushrush, G., "The Interaction of Geology, Weather and Home Construction on Indoor Radon in Northern Virginia and Southern Maryland" Paper presented at "Radon in the Northeast: Perspectives and Geological Research" Albany, NY, May 31 - June 2, 1988.

Munroe, M., "80,000 Canadian Homes May Have Excessive Radon", St. John, N.B. Telegraph Journal, Jan. 9, 1987.

Mushrush, G. W., and Mose, D. G., "Year-Long Radon Survey in Virginia and Maryland: Results from 1500 Homes", The 1988 Symposium on Radon and Radon Reduction Technology, Denver, Oct. 18-21, 1988.

NCRP Report No. 78 Evaluation of Occupational and Environmental Exposures to Radon and Radon Daughters in the United States, May 31, 1984, 204 p., 11 chapters, 296 Ref.

Nazaroff, W. W., Doyle, S. M., Nero, A. V., Sextro, R. G. "Potable Water as a Source of Airborne Airborne Radon-222 in U.S. Dwellings: A Review and Assessment" Lawrence Berkeley Lab. (U. of California) Preprint LBL-18154, Dec. 1985, submitted to Health Physics 35 p., 5 Tables, 6 Figures, 62 Ref.

Nero, A. V., "Radon in Dwellings: Exposure and Risk Analysis", 1985, 4 p., 4 Ref.

Nero, A. V., "Indoor Concentrations of Radon 222 and its Daughters: Sources, Range, and Environmental Influences", Presented at the Seventh ORNL Life Sciences Symposium on Indoor Air and Human Health, Knoxville, TN, Oct. 29-31, 1984, and to be published in the Proceedings, April 1985, 24 p., 37 Ref., 6 Fig.

Nero, A. V., Lowder, W. M., Guest Editors, Health Physics, "Special Issue on Indoor Radon" Vol. 45:2 August 1983, 300 p., 38 refereed papers, 547 Ref.

Nero, V. Jr. "Controlling Indoor Air Pollution" SCIENTIFIC AMERICAN, Vol. 258:5, May 1988, pp. 42-48, 9 Fig. and Tables.

Osborne, M. C., "Four Common Diagnostic Problems that Inhibit Radon Mitigation" JAPCA, May 1987, Vol. 37:5, pp. 604-606.

Payne, D., "The Menace of Indoor Pollution", Reader's Digest, September 1986, pp. 15-20.

Piersol, P., Riley, M., Lubun, M., "Radon and Air Infiltration: Instrumentation Evaluation and Field Surveys for the R-2000 Super Energy Efficient Program" presented at APCA Annual Meeting, Minneapolis, MN, June 1986, paper, 86-81.7.

Prichard, H. M., Gesell, T. F. "Rapid Measurements of 222Rn concentrations in Water with a Commercial Liquid Scintillation Counter" Health Physics Vol. 33, 1977, pp. 577-581.

Purcell, G. G., "Electric Power Research Institute Indoor Air quality Program" pp. 584-585, 3 Ref., Trans. APCA, Ibid

Radford, E. P. "Potential Health Effects of Indoor Radon Exposure" ENVIRONMENTAL HEALTH PERSPECTIVES, Vol. 62, pp. 281-281, 1985, 23 Ref., 1 Fig., 3 Tables.

Radiation Safety Bulletin 4:1, April 1986, 8 p., All about Radon Published by CAIRS, Toronto, Ontario.

Radon Reporter, AARST, Vol. 1, No. 2, Spring 1988.

Radon Reduction in New Construction: An Interim Guide, August 1987, Prepared by USEPA Offices of Air and Radiation and Research and Development, OPA-87-009, 8 pages, 4 Fig.

Rivers, M. E., Brown, L. R., and Iwansi, M. L., "Indoor Air Quality Activities of the Tennessee Valley Authority" Paper 86-11.7 at 79th Annual Meeting of the Air Pollution Control Assoc., June 23-27, 1986, Minneapolis, MN.

Ronca-Battista, M., Magno, P., Windham, S., Sensintaffer, E. "Interim Indoor Radon and Radon Decay Product Measurement Protocols", February 1986, EPA 520/1-86-04, 62 pages, 17 Ref.

Sachs, H. M., "The Incidence, Recognition and Mitigation of Radon-based Problems in Residences", 1984, 47 pages, 12 Fig., 7 Tables.

Sentis, R. R., Wagner, E. P. "Objectives and Results of Radon Surveys in Saskatchewan" Indoor Air Quality in Cold Climates: Hazards and Abatement Measures, Ibid pp. 105-115, 3 Fig, 11 Ref.

Sextro, R. G., "Control of Indoor Radon and Radon Progeny Concentrations", ASHRAE Trans., 91: Part 2, 1963-1979 (1985), 46 Ref., 1 Table, 8 Fig.

Steinhausler, F., Hofmann, W., Pohl, E., and Pohl-Ruling, J. "Radiation Exposure of the Respiratory Tract and Associated Carcinogenic Risk due to Inhaled Radon Daughters" Health Physics 45:2 August, 1983, pp. 331-337.

Stevens, Wm. K., "Big Increase Expected in Radon Pollution Suits", NY TIMES, Sept. 28, 1986.

Swallow, W., "Radon Levels Called Surprising" WASHINGTON POST, March 28, 1987, p. F1.

Swallow, W., "Bills Target Radon Threat", Washington Post, March 21, 1987.

Swedjiemark, G. A., Buren, A. and Mjones, L., "Radon Levels in Swedish Homes: A Comparison of the 1980s with the 1950s" Radon and Its Decay Products Amer. Chem. Soc., 1987, pp. 84-96, 21 Ref., 2 Tables, 3 Figs.

Taniguchi, H.; "Radon-222 and Its Daughters in Buildings at Uranium City, Saskatchewan", Radon Workshop, February, 1977, Report HASL-325, July 1977, pp. 141-148, 1 Table, 3 Ref.

Taniguchi, H.; "Present Practices of the Department of National Health and Welfare for the Area Monitoring of Radon and Daughter Products", Proc. of the Specialist Meeting on Personal Dosimetry and Area Monitoring Suitable for Radon and Daughter Products, Elliot Lake, Canada, 4-8 October, 1976, pp. 251-254, 6 Ref.

Taniguchi, H., Vasudev, P., "Radon and Radon Daughters Due to Natural Uranium Occurrences in a Rural Ontario Community", Natural Radiation Environment III. (T.F. Gesell and W. M. Lowder, Eds.) Doe 51 Symposium Series, Conf. 78-0422, 1980, 623-1632, 5 Fig., 9 Ref.

Tanner, A. B. "Radon Migration in the Ground: A Supplementary Review", in Natural Radiation Environment III, Sumposium Proceedings, Houston, TX., April 23-28, 1978, Gessel, T. F. and Lowder, W. M., (Eds.), Vol. 1, pp. 5-56, USDOE Rept. CONF-780422, NTIS., 1980, 255 Ref.

Tanner, A. B., "Radon Migration in the Ground a Review", The Natural Radiation Environment, Univ. of Chicago Press, 1964, pp. 161-190, 164 Ref., Adams, J. A. S., Lowder, W. M. editors.

Tanner, A. B., "Indoor Radon and its Sources in the Ground", U.S. Dept. of the Interior Geological Survey, Open-file Report 86-222, 1986, 5 p., 5 Ref.

Tanner, A. B., "Geological Factors That Influence Radon Availability", Indoor Radon, Proc. of APCA Intern. Specialty Conf., Philadelphia, Pa., Feb. 24-26, 1986: APCA Pub. SP-54 pp. 1-12, 1986, 15 Ref., 3 Fig.

Turk, B. H., Harrison, J., Prill, R. J. and Sextro, R. G., "Interim Report on Diagnostic Procedures for Radon Control", LBL-23089 March 1987, 58 p., 10 Fig., 23 REf., 3 Tables.

Turk, B. H., Prill, R. J., Fisk, W. J., Grimsrud, D. T., Moed, B. A., and Sextro, R. G., "Radon and Remedial Action in Spokane River Valley Residences: An Interim Report", March 1986, 23 p., 3 Tables, 5 Fig., 12 Ref., LBL-21399.

U.S. General Accounting Office "Air Pollution: Hazards of Indoor Radon Could Pose a National Health Problem" Report to the Pennsylvania Congressional Delegation House of Representatives, June 1986, 55 pages, GAO/RCED-86-170.

Walkinshaw, D. S., "Indoor Air Quality in Cold Climates: Hazards and Abatement Measures" Summary of an International Specialty Conference JAPCA 36:3, March 1986, pp. 235-241, 4 Ref.

Walkinshaw, D. S., "Indoor Air Quality: Issues and Opportunities" Engineering Digest June 1986, p. 28-34, 60 Ref. (From Editor).

Walkinshaw, D., Ed. "Indoor Air Quality in Cold Climates: "Hazards and Abatement Measures" Trans. of the Air Pollution Control Assoc. Papers from April 1985 Conference in Ottawa, 622 p., 57 papers, Pub. April, 1986, by APCA.

Wrixon, R. D., "Human Exposure to Radon Decay Products", Atom 352, Feb. 1986, 2 Figs., 5 Tables, 13 Refs., pp. 2-6.

APPENDIX 1 - Individual Home Radon Test Packet Results

PACKET	CODE	RADON (pCi/L)
66980	C	3.92
66986	C	2.70
66998	C	0.83
67000	C	4.75
166705	C	1.15
166754	C	4.24
166758	C	3.36
166794	C	1.30
166964	C	2.29
168802	C	4.54
168805	C	4.88
168807	C	8.27
168808	C	1.34
168809	C	2.21
168811	C	1.03
168814	C	3.17
168816	C	1.26
168818	C	3.62
168820	C	45.58
168821	C	2.74
168822	C	4.10
168823	C	9.88
168824	C	6.68
168825	C	1.60
168826	B	28.16
168832	C	34.00
168833	C	2.18
168834	C	3.47
168835	C	0.52
168837	C	4.83
168838	C	15.40
168840	C	10.98
168841	C	1.59
168842	C	1.29
168844	C	3.21
168845	C	1.90
168850	C	9.41
168852	C	2.68
168854	C	0.90
168857	C	2.78
168858	C	1.94
168860	C	1.22
168862	C	2.12
168863	C	1.58
168864	C	3.19
168866	C	3.14
168869	C	2.83
168870	C	3.22
168872	C	40.41

"A" Exposed before winter
"B" Winter exposures in same homes as "A" packets
"C" Winter exposures non"A" houses

PACKET	CODE	RADON (pCi/L)
168873	C	1.20
168874	C	2.09
168878	C	4.43
168881	C	3.09
168882	C	3.50
168883	C	0.40
168884	B	4.35
168885	B	4.42
168886	B	0.57
168887	B	2.88
168888	B	0.48
168890	B	7.61
168891	B	3.63
168892	B	6.20
168893	C	3.51
168894	B	1.90
168897	B	2.83
168898	A	3.94
168899	A	1.42
168900	A	2.15
168901	A	14.68
168902	B	1.13
168903	A	1.87
168904	B	0.67
168907	A	0.86
168910	A	3.63
168911	B	0.81
168912	A	0.45
168913	B	0.91
168914	A	1.30
168915	A	0.73
168916	B	0.86
168917	C	16.00
168918	B	3.07
168919	A	1.76
168922	A	2.40
168923	B	4.84
168924	B	0.70
168925	B	0.82
168928	A	4.39
168929	A	0.33
168931	B	4.81
168932	A	7.09
168934	A	9.96
168935	A	0.98
168936	B	14.86
168936	A	12.30
168937	C	5.31
168938	A	3.45

PACKET	CODE	RADON (pCi/L)
168940	B	2.30
168941	B	2.40
168942	B	1.56
168944	A	0.47
168945	A	1.49
168946	B	2.26
168947	B	0.45
168948	B	2.35
168949	B	2.51
168950	A	9.99
168951	A	1.36
168953	B	3.40
168954	B	3.89
168955	B	1.79
168957	A	1.58
168957	B	2.60
168958	A	8.56
168959	A	2.70
168960	B	1.83
168961	B	11.98
168964	A	3.51
168965	B	1.70
168966	B	3.36
168967	B	3.85
168968	B	1.75
168969	B	1.88
168970	B	4.21
168974	B	3.48
168975	B	20.57
168976	B	0.54
168977	B	4.03
168978	B	15.00
168979	B	10.94
168981	C	5.77
168982	B	5.57
168983	B	3.79
168984	B	8.86
168986	B	1.23
168988	A	25.00
168990	C	2.85
168991	C	14.04
168993	C	3.53
168996	C	2.28
168997	C	6.39
169000	C	10.24
169001	A	0.97
169002	A	5.04
169003	C	30.00
169004	C	6.33

PACKET	CODE	RADON (pCi/L)
169006	A	0.82
169009	A	6.14
169010	C	4.32
169012	C	1.17
169015	A	2.95
169019	C	2.59
169020	A	3.64
169022	C	1.30
169023	C	1.30
169024	C	2.13
169025	A	17.40
169026	C	1.49
169027	C	0.73
169029	A	2.17
169032	A	0.52
169033	A	1.38
169034	A	0.83
169039	A	2.92
169040	A	2.13
169044	A	2.10
169045	A	8.53
169046	A	2.23
169047	A	3.51
169048	A	3.62
169052	A	1.20
169053	A	3.49
169060	C	1.15
169067	A	2.70
169069	A	4.46
170920	C	1.93
171103	C	6.60
171171	C	8.77
171258	C	2.25
171258	C	2.25
171266	C	1.29
171678	C	2.40
171682	C	6.90
200001	C	3.22
200002	C	1.23
200003	C	3.31
200004	C	2.47
200005	C	11.80
200006	C	2.59
200007	C	4.52
200008	C	1.79
200009	C	20.50
200010	C	2.57
200011	C	8.46
200012	C	2.22

PACKET	CODE	RADON (pCi/L)
200015	C	2.48
200016	C	1.76
200019	C	1.45
200020	C	1.41

APPENDIX 2

"RADON" DATABASE DESCRIPTION

The radon database contains one data field for every data item on the questionnaire (see the database structure in file FILESTR.TXT). All variable information (i.e. name, address, etc.) is stored in character fields. The questionnaire data fields (i.e. house type, water supply, etc.) are stored as single digit numeric fields. The questionnaire data was transferred to the database by entering a "1" in those items checked off by the home owner (and thus those not checked off remain as zero's). For example, if the home owner designated the age of his house by checking the '5 - 10 years' space, the AGE3 field in the database would be coded as 1 , and the remaining fields relating to the age of the house (AGE1,AGE2,AGE4) would be left at 0 (zero). In this manner, to select a specific range of this data within the database, one need only specify which fields contain a 1.

EXAMPLE: To select all houses over 20 years old, with heavy insulation and using a private well, the program coding would be:

```
AGE4=1 .AND. INSUL1=1 .AND. WATER2=1
```

The CODE field is a character field, and must be enclosed in quotes if specified in a data range e.g. CODE="B".

Three index files have been set up to order the file for specific program runs, and they should always be open when using or manipulating the database.

VALUE.NDX	Ordered in increasing value of radon level.
NAME.NDX	Ordered alphabetically by home owner name.
RADON.NDX	Ordered by packet designation number.

To open the database with all indexes open: 'USE RADON INDEX VALUE,NAME,RADON'

A format file (RADON.FMT) has been set up for inputting/editing/viewing the data record by record. To use the format file, open the database file and any indexes, open the format file, and then issue the action command.

EXAMPLE: To edit a record using the format screen:

```
USE RADON INDEX VALUE,NAME,RADON
SET FORMAT TO RADON
EDIT
```

"TABULATE" PROGRAM DESCRIPTION

The program used to produce the selected tabulations of the data (TABULATE.PRG) allows the user to specify one or more data range selections for each run. The program prompts the user for the data range coding paramaters (as described above), and the title to be printed, for each selection. The user is given the choice of saving the selection criteria in a file for identical runs at a later date.

The program performs calculations on the data based on the user's criteria and prints a standard output tabulation form for each case. In all cases, only those records with non-zero radon level values are considered by the program.

Each data range selection takes from 3 to 5 minutes to calculate and print. (using an IBM PC, and a 250 record database.)

The program and database have been developed in DBASEIII.

"RADON" FILE STRUCTURE

FIELD NAME	TYPE	DESCRIPTION
NAME	CHARACTER	
ADDRESS	CHARACTER	
CITY	CHARACTER	
ZIP	CHARACTER	
DATE	DATE	
PHONE1	CHARACTER	HOME PHONE NUMBER
PHONE2	CHARACTER	WORK PHONE NUMBER
AGE1	NUMBER	HOUSE LESS THAN 5 YEARS OLD
AGE2	NUMBER	HOUSE BETWEEN 5 AND 10 YEARS OLD
AGE3	NUMBER	HOUSE BETWEEN 10 AND 20 YEARS OLD
AGE4	NUMBER	HOUSE OVER 20 YEARS OLD
TYPE1	NUMBER	1 STORY
TYPE2	NUMBER	2 STORY
TYPE3	NUMBER	3 STORIES OR MORE
TYPE4	NUMBER	APARTMENT BUILDING
TYPE5	NUMBER	BASEMENT
TYPE6	NUMBER	CRAWL SPACE
TYPE7	NUMBER	SLAB
TYPE8	NUMBER	STORIES
TYPE9	NUMBER	BASEMENT & CRAWL SPACE
TYPE10	NUMBER	SLAB & CRAWL SPACE
HEAT1	NUMBER	FORCED AIR
HEAT2	NUMBER	BASEBOARD HOT WATER
HEAT3	NUMBER	STEAM
HEAT4	NUMBER	OIL
HEAT5	NUMBER	ELECTRIC
HEAT6	NUMBER	PROPANE
HEAT7	NUMBER	WOOD
HEAT8	NUMBER	COMBINATION
WATER1	NUMBER	CITY WATER
WATER2	NUMBER	PRIVATE WELL
INSUL1	NUMBER	HEAVY INSULATION
INSUL2	NUMBER	MEDIUM INSULATION
INSUL3	NUMBER	LIGHT INSULATION
BASE1	NUMBER	FINISHED BASEMENT
BASE2	NUMBER	3 BEDROOM BASEMENT
BASE3	NUMBER	UNFINISHED BASEMENT
BASE4	NUMBER	1 BEDROOM BASEMENT
BASE5	NUMBER	2 BEDROOM BASEMENT
EXHAUST1	NUMBER	KITCHEN EXHAUST FAN
EXHAUST2	NUMBER	BATHROOM EXHAUST FAN
SQUARE1	NUMBER	UNDER 1000 SQ.FT.
SQUARE2	NUMBER	BETWEEN 1000 AND 2000 SQ.FT.
SQUARE3	NUMBER	OVER 2000 SQ.FT.
CODE	CHARACTER	CASE SPECIFIER (A, B or C)
PACKET	NUMBER	PACKET NUMBER
CHARCOAL	NUMBER	CHARCOAL MASS
RADON	NUMBER	RADON LEVEL (pCi/L)

APPENDIX 3 - Test Result Notification Form

Dear Radon Test Customer: (Thank you for your help on this research program. S.T. Friedman)

Your radon sampler has been analyzed, and we've found the following results:

1) _____ pCi/L 2) _____ pCi/L 3) _____ pCi/L

CODE #: _____

The abbreviation pCi/L means picoCurie per liter of air, the most common method of expressing radon/air concentrations. A picoCurie is a trillionth of a Curie, a unit of radioactivity. The following paragraphs explain what your result means, how you should interpret it, and what you might do to follow up on the test. If you have a problem interpreting your results, you may contact our technical service department at 452-1414 between 8:00 a.m. and 6:00 p.m. and 457-0232 after 6PM and on weekends.

Variations in Radon Levels

During normal weather, indoor radon levels may rise and fall by a factor of two on a daily cycle--e.g., from 5 pCi/L to 10 pCi/L in 24 hours. During stormy weather, the levels will change even more drastically. The test results we've sent you are as they should be, an average of the radon concentrations in the area tested during the period the sampler was exposed. Bear in mind, if you are doing comparison testing or are averaging a series of tests, that any radon test is ONLY the average of the levels present during a specific period of time. Conditions during subsequent tests may not be the same.

(The following is condensed from the latest radon testing protocols being published by the EPA)

Conducting National Screening Measurements for Radon

Screening measurements should identify houses which contain high concentrations of radon that have the potential for causing increased risk of lung cancer. From a public health viewpoint, it is important to quickly identify such houses so that exposures can be reduced.

Screening measurements should be made in the lowest (potentially) livable area in the house. The highest concentrations of radon will usually be found in a room closest to the underlying soil. Therefore, a screening measurement should be made during closed-house conditions to ensure that the information obtained reflects the potential maximum concentrations to which the house occupants may be exposed. A measurement made under these conditions is less likely to miss a house where high concentrations may reach a living area. Conversely, if the results of a worst case screening measurement are very low, there is a high probability that the long-term average concentrations in the general living area of that house are also low. This is because average concentrations in living areas are about one-third of the level found in a basement (or other worst case measurement) during closed-house conditions.

If a house has, as a result of a screening measurement, been identified as having the potential for high exposures, a follow-up measurement should be made before the homeowner makes any decisions on the need for long-term remedial action. Follow-up measurements can be used to estimate the long-term averages. Then these averages can be compared with the guidelines given in terms of safe annual exposure concentrations and used to determine the maximum health risk incurred by the occupants.

Using Your Screening Measurement Results

If the measurement results (from a test made under worst case conditions) are less than 4 pCi/L, there is a high probability that the annual average concentrations in the general living areas on non-basement floors of the house are less than 4 pCi/L. Exposures in this range (1 to 4 pCi/L) do present some risk, to the more sensitive occupants, of contracting lung cancer. However, reductions of concentrations this low may be difficult, and sometimes impossible, to achieve. If the screening measurement result is less than 4 pCi/L, a follow-up measurement is not necessary unless the room in which the test is made is used as a living area. This may be the case if there is a bedroom in the basement, or if the house has no basement and the test was made on the ground floor. Another test, conducted during cold weather, when continuous closed-house conditions are easily maintained, could be used to verify and average the current test results.

If the results of the test are between 4 and 20 pCi/L, the occupants should be aware that there is concern about the long-term exposure to these radon concentrations, but that there will probably be no large increase in risk with an additional 12 months of exposure. The occupants should consider making four measurements at three month intervals in order to determine the annual average and, therefore, their long-term exposure levels. Guidance for action to reduce radon levels as well as estimations of health risk are usually expressed in terms of annual average concentrations. (Measurements made to estimate annual averages should be made under normal living conditions in the major living areas.)

If the test results (of a worst case) are between 20 pCi/L and 200 pCi/L, a follow-up measurement, taken in the main living area, should be made within the next few weeks because the occupants may be exposed to dangerously elevated levels of radon. An annual measurement alone is usually not recommended because an additional 12 months of exposure could cause a significant increase in health risk.

If the results are greater than 200 pCi/L, the state health department or regional EPA office should be contacted for advice on immediate reductions in radon levels.

(Although the U.S. EPA is recommending that immediate action be taken at 200 pCi/L, some other agencies are considering 100 pCi/L as the level requiring immediate response. Call your state's health department or radiation control board for their recommendations.)

How To Select The Rooms To Be Used For Follow-Up Measurements

The test should be made in at least two main living areas (at two levels if more than one floor). Choose a frequently used room, such as a family room, den, playroom, or bedroom. A bedroom is a good choice because at least one occupant spends one-third of the year there.

If there are children less than 12 years old in the house, it is especially important to measure the concentrations in their bedrooms or in another area where they spend a lot of time. Evidence suggests that children may be more sensitive than adults to the effects of inhaled radon decay products.

The measurements should not be made in a kitchen, because of the likelihood that the range-exhaust fan system and the usually high traffic will cause abnormal changes in the radon levels. In addition, measurements should not be made in a bathroom, because relatively little time is spent in a bathroom. If radon in the water is thought to be one of a home's major radon contributors, then additional tests made in the bathroom could be used to determine a possible contribution from the water supply. Call SCAT for suggestions on a testing procedure that may locate water-bound radon. (NOTE: Radon is NOT usually found in community water systems where the water has been through a water treatment process. However, water from a private deep-well system may be suspect.)

LIMITATION OF LIABILITY: While we, at SCAT, make every effort to maintain the highest possible quality control and include several checks and verification steps in our procedures, we make **NO WARRANTY OF ANY KIND, EXPRESSED OR IMPLIED**, for the consequences of erroneous test results. Before any action is taken on the basis of the test result reported **WE RECOMMEND THAT FURTHER MEASUREMENTS BE MADE**. Neither SCAT nor any of its employees or agents, shall be liable under any claim, charge, or demand, whether in contract, tort, or otherwise, for any and all loss, cost, charge, claim, demand, fee, expense or damage of any nature or kind arising out of, connected with, resulting from, or sustained as a result of any radon test requested.

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$29.50 @ for one
$25.00 @ for 2-9 and
$22.50 @ for 10 or more.

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For packet drop off
79 Pembroke Crescent
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APPENDIX 4

Testing of Radon Levels in Water

The technique used in Maine involves the use of a liquid scintillation detector. This is a system wherein small liquid samples are mixed with a socalled scintillation "cocktail" so that when a particle of radiation is emitted it creates a pulse of light which is picked up by a photo detector surrounding the transparent bottle in which the samples are run automatically through the machine. Because the sample is in effect surrounded by sensitive monitoring devices, the counting efficiency is excellent and because the volume is relatively small it is easy to keep a relatively low background environment by providing adequate shielding to prevent externally produced particles from interacting with the counting medium. These systems have the virtue of being able to handle many samples providing a printout of the test results and of being easily automated so that counting can be done with no one present. A problem of course, for the small company, is that there is a substantial investment $10 - 20,000 required for such a system and that this cannot be justified unless a substantial number of test specimens are to be evaluated.

From an environmental viewpoint, one usually finds that the great majority of test samples from wells near a nuclear reactor such as Point Lepreau or from other places in the province have a very low level of radioactivity. Normally the concern is with uranium or radium or perhaps radioisotopes produced by the fission process. Because the level of such radioisotopes is extraordinarily low, sample counting is done for an extended period of time

perhaps 100 minutes per sample and with 99%+ of the samples providing no radiation above background. In the situation with radon in water, however, in wells, past experience suggests that there would be some samples with quite substantial counting rates. In any event the sensitivity of the liquid scintillation method is considerably greater than that of the method previously used with samples that had to be evaporated.

With the very substantial co-operation of the Fredericton based Health Physics Laboratory of The New Brunswick Electric Power Commission, and thanks to the supplying of a small standard radium sample by the Health Physics Laboratory in Maine, it was possible to develop a unique technique for the Province of New Brunswick: a liquid scintillation method for the determination of radon levels in water samples obtained from wells. The use of the standard was required in order to calibrate the system. A standard radium solution allowed to remain fixed for a period of several weeks will come to equiliberium with the radon that is grown in; that is, the radium produces radon which in turn decays and at some point one has an equiliberium between the amount being produced and the amount decaying. By subdividing the standard into various dilutions one is able to generate a curve that shows how many disintegrations there are per unit volume of the (sample and diluent).

In turn then, with other samples, making appropriate allowances for differences in the energy of the various alpha particles, for the fact there are other isotopes present than radon-222 (the primary one of concern) it is possible to provide, in effect,

a calibration factor so that a net counts per minute per unit volume can be converted into concentration of radon per unit volume of water. This was done.